

Asamushi, Japan - Marine Biology Sta.

Bulletin

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC SERVICE

-4)

5(1-

海洋生物時報

第五卷 第一 乃至 四號

昭和二十七年三月

BULLETIN
of
THE MARINE BIOLOGICAL STATION
OF ASAMUSHI

Vol. 5, Nos. 1-4

(March, 1952)

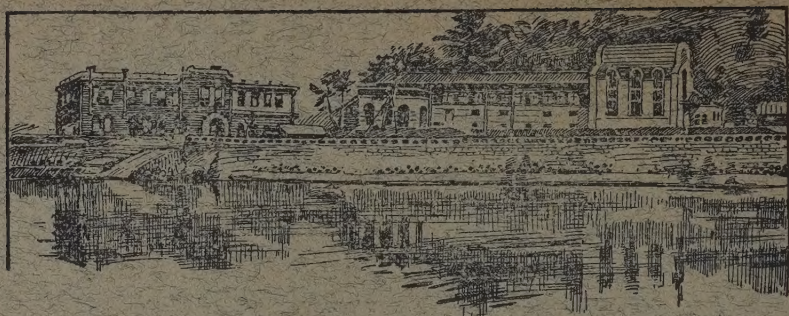


Asamushi, Aomori Prefecture

JAPAN

東北大學淺虫臨海實驗所

青森縣淺虫



The Marine Biological Station of Asamushi

The Marine Biological Station is situated at Asamushi, Aomori Prefecture, one of the most delightful summer resorts in northern Japan, providing not only an excellent sea bathing, but also hot spring close to the shore. The station is near the Asamushi Railway Station, on the Tôhoku Main Line, a journey of about 22 hours from Tôkyô.

The Marine Biological Station was founded in July 1924 as an extension of The Institute of Biology, Tôhoku University. Although the primary object in building the station was to facilitate the work of the students, as well as the faculty, of Tôhoku University, it welcomed from the start all outside investigators. We welcome investigators at any season, though naturally summer and autumn are the season of greatest activity. The boarding house and official residences are open all the year round for the convenience to any one wishing to do research work.

The laboratory is well equipped with various kinds of apparatus commonly used for biological purpose. All the laboratory materials are free for use, except an excessive amount of expensive matter would be used. Visiting investigators are requested to communicate beforehand the nature of their research, duration of stay etc. to the director. Investigators are permitted to stay in the boarding house of the station, provided the cost of meals is paid.

Prof. Seiji Kokubo.

Director of
Marine Biological Station of Asamushi.

All communications intended for our publications should
be addressed to Prof. S. Kokubo, Marine Biological Station.
Asamushi, Japan.



Marine Biological Station of Asamushi. •

Frontispiece

Marine Biological Station of Asamushi

Viewed from the south-east height

海 洋 生 物 時 報

第 五 卷

第 一 ～ 四 號

B U L L E T I N

of

THE MARINE BIOLOGICAL STATION OF

ASAMUSHI

Vol. 5, Nos. 1-4

(March, 1952)

Contents

1. Results of the Observations on the Plankton and Oceanography of Mutsu Bay during 1950, Reference being made also to the Period 1946-1950..... by Seiji Kokubo... 1
2. On the Dissolved Oxygen and Chlorinity of the Water of Mutsu Bay during 1950. by Toshinobu Tokui... 55
3. Report on the Water Temperature of Mutsu Bay during 1950. by Teruyoshi Kawamura... 58
4. Seasonal Change of the Phosphate and Silicate of the Water of Mutsu Bay during 1950. by Tetsusaburô Okitsu... 61

Results of the Observations on the Plankton and Oceanography of Mutsu Bay during 1950, Reference being made also to the Period 1946-1950.

I. General Part and Diatoms.

By

Seiji Kokubo.

I. Introduction	1
CHAPTER I, General Part	
II. Observations on the Plankton	2
(A) Method and Apparatus	3
(1) Station	3
(2) Plankton net	4
(3) Collection	5
(B) Results	6
(1) General tend of the seasonal change of plankton	6
(2) Seasonal and annual change of the quantity of plankton during five years of 1946-1950.	8
(3) Seasonal and annual change of the plankton association	10
(a) Seasonal change in 1950	10
(b) Yearly change during the period from 1946-1950	14
CHAPTER II, General survey of the plankton organisms	21
(A) Diatoms	22
(1) Chaetoceros	23
(a) Power of the vegetation of Chaetoceros	24
(b) Chaetoceros as indicator species	25
(c) Autecology of Chaetoceros	27
(2) Asterionella	38
(3) Bacteriastrium	39
(4) Cerataulina	41
(5) Coscinodiscus	41
(6) Climacodium	43
(7) Dactyliosolen	44
(8) Eucampia	44
(9) Guinardia	45
(10) Hemiaulus	45
(11) Hemidiscus	45

(12) <i>Lauderia</i>	46
(13) <i>Leptocylindrus</i>	46
(14) <i>Nitzschia</i>	46
(15) <i>Rhizosolenia</i>	46
(16) <i>Skeletonema</i>	49
(17) <i>Thalassionema</i>	50
(18) <i>Thalassiothrix</i>	51
III. Summary	51

I. INTRODUCTION

This report covers the fifth year of the Bulletin of the Marine Biological Station of Asamushi. The bulletin has so far been issued quarterly as far as the circumstances allow. This year, however, publication four times was hardly possible mainly because of economic reasons, and on this account the issues of Vol. 5 were contracted to this sole number. But such a condensation of the description of one year's observation happened to lead us to make comments upon the outline of the biological oceanography of Mutsu Bay. This is indeed a good opportunity of interpreting general ecology of plankton and its relation to hydrographic conditions, as such a discussion has not been written since our regular observations have started. Therefore, in this number the data of 1950 are discussed, comparison being made with those of the five preceding years, and when possible older data is also referred to.

Before entering into particulars it should be noted that the present investigation affords the data to reveal: (1) in what manner has been the seasonal change of plankton in 1950, and how it differed from the seasonal changes of the three preceding years; (2) the nature of the immigration of tropical plankton from without into Mutsu Bay, e.g. the season of immigration and kinds of immigrants; (3) the presence of the plankton organisms which signify the strength or influence of warm or cold water current; (4) how many and what kind of zoo- and phyto-plankton occur in Mutsu Bay; (5) whether the present data give some suggestions regarding the northernmost termination of the distribution of the tropical plankton in the Japan Sea.

By the way of considering biological oceanography of Mutsu Bay some apparent features of the fisheries events will be stated here, as they are also concerned with hydrography. In Mutsu Bay, 1950, the catch of Tai (*Pagrosomus major*) and Suzuki (*Lateolabrax japonicus*) during April - May was so rich that every market of the villages and towns was full of these fish. Such a rich catch might certainly be caused by the warm temperature in these months. Immediately after this, sardine fishery occurred showing but a poor catch. During the summer the fishery of Scallop culminated in August with a rich catch, though the size of the

Scallop was smallish. The catch of the cuttle-fish in autumn turned out to be very poor. On entering winter the cod fishery, which is the most important fisheries resource in Mutsu Bay, showed a serious decline this year, the catch being almost nothing. This decline might arise from no runs of this fish from Tsugaru Strait. As regards such matters of fishery special attention has been and is being paid by us from the view point of oceanography (Kokubo & Kawamura, 1949).

CHAPTER I, General Part.

II. OBSERVATIONS ON THE PLANKTON.

The plankton of Mutsu Bay has long been studied and reported by the present author (Kokubo, 1931a, 1932b, 1934, 1938, 1939, 1945-1949, 1950). Some of these works stressed the quantitative relation; others focussed interest on the vertical or seasonal distribution. In the present study importance has been attached to species enumeration, special attention having been centered on the Copepoda and Diatoms. This is because these two groups are the most important ones in both specific and quantitative abundance, also because the Diatoms which composes the bulk of phytoplankton, governs the primary production of organic matter in the sea, and because the Copepoda which always predominates in zooplankton plays major part in the production of animal protein in the sea; consequently the study of these two groups involves the most pertinent measures of the productivity of the sea.

A further importance of these groups is that some of them inhabit only warm water, the others only cold water. This is why some plankton are utilized as the indicator of a certain ocean current. Frost (1930) and Russel (1939) reported the use of plankton organism as an indicator of hydrographic conditions. In the present study the adequacy of some species of these two groups for this purpose is also well recognized.

(A) Method and Apparatus.

The method of collection was the same as that carried out in the former investigations (Kokubo, 1945-1949), viz., at a given station the collections were made horizontally and vertically by using an ordinary plankton net, the hydrographical observations having been made at the same time.

(1) STATION. To make the conditions of collection comparable a regular station was fixed at a point off coast from our station. This station is situated 1 mile off coast, measuring about 31 meters in depth, with sandy mud bottom. This station kept the clarity of the sea water well through all seasons, being scarcely disturbed even by strong wind. The colour of the sea water of this station usually changed around No. 4 of Forel's scale, its change being due to

the plankton condition. The transparency (Secchi-disk reading) of sea water at this station sometimes became as high as 25 meters and decreased to as low as 2 meters according to the quantity of the plankton (Kokubo, 1932a). As regards the water temperature distinct stratification occurs during summer, and indirect stratification during winter, though the latter is not marked and appears only when the sea is calm.

(2) PLANKTON NET. The plankton net used for collection was of common type. The diameter of this net was 30 cm, the length 100 cm, consisting of "Müller gauze No. 14", and at its lower end was attached a brass bucket of 5 cm in diameter provided with a stopcock.

The section area of the entrance of this net was about 720 sq cm. and filtration surface was about 4760 sq cm., and hence the ratio of these areas was 1 : 6.5. Therefore when this net was towed 30 meters it had to pass through a water column of 2160 litres, provided that the resistance of the mesh of the net against water is none.

Actually, however, it is considered that the quantity of water actually filtered is by far less than the quantity calculated as above. Formerly such relations were studied in particular by Kokubo (1931a) with the result that the ratio of these quantities, viz., the filtration coefficient of net, is unexpectedly large, at least so far as the ordinary net of No. 25 gauze is used, especially when the plankton is abundant. But the plankton net used in the present study is made of No. 14 gauze whose mesh is incomparably larger than that of the No. 25 gauze. Therefore an experiment was carried out to test the filtration rate of this net.

In Kokubo's (1931a) former experiment the filtration coefficient was determined by comparing the result of pump collection and net collection. Instead, in the present experiment a small flowmeter was used (Rep. 1950) which was

Times of exp.	Readings of flowmeter	
	Net with flowmeter	Flowmeter only
1	6.0	15.5
2	5.5	14.5
3	5.5	15.0
4	5.5	15.0
5	4.5	15.0
6	6.0	15.0
7	5.0	14.5
8	5.5	15.0
9	4.5	15.0
10	5.5	15.0
Mean	5.3	15.0

fastened at the centre of the mouth of the net. The net with this flowmeter was vertically towed from the depth of 30 meters up to the surface, and the reading of the flowmeter was recorded. Next, the flowmeter, detached from the net was

towed vertically in like manner, and the scale reading was recorded. These two sets of readings were compared as follows.

From the above it follows that the ratio of both readings, viz., filtration coefficient, is about 3. But this figure can not be hastily used, because in this experiment it is questionable whether the speed of water passing through the flowmeter is equal to that of the water passing other parts of the entrance. But the reason why such a test was made is that in some cases this method will serve to determine the filtration coefficient of a net. For instance in case a net of large filtering power is used the above two readings will coincide with one another, thus indicating that the filtration coefficient is 1. This must be correct as it is certain that the water passing outside of the flowmeter is never slower than the water passing through the flowmeter. At any rate it can also be thought that as is well known the filtration coefficient is very variable by nature, so that the above figure may be taken as a rough measure of the coefficient. In the present investigation, however, the above experiment was made for purpose of a mere reference, and hence the calculation due to this coefficient is made tentatively.

(3) COLLECTION. The collections were made twice a month at a regular station on the 1st and 15th every month as far as the weather made it possible. Each time a vertical haul and three horizontal hauls were carried out. For the vertical haul the net above mentioned was lowered down to 31 meters depth, and then it was hauled up to the surface at the speed of 0.5 meters per second.

As will be seen in a later page (Table 1) the quantity obtained by this vertical collection ranged between the minimum of 6 cc to the maximum of 205 cc, thus suggesting that this method is well suited for the present purpose.

For the quantitative collection of plankton the author (Kokubo, 1931a) once used a pump, making comparison with the quantitative net. Shortly thereafter a settling method was extensively employed (Kokubo, 1939) in the study of microplankton. The author was led to consider that in the long run, for routine work, collection by ordinary net is also worth while to practice, at least when the comparative result is mainly hoped for. For this reason the author resolved to employ the vertical collection above mentioned for the present purpose. Needless to say the result obtained by this method may not depict the absolute figure of the plankton quantity as can be accepted from what was mentioned elsewhere concerning the filtration coefficient of the net.

The horizontal collections were made for five minutes each time in tow ways, one being surface collection and another being by towing through the layer of 10 meters. For the latter purpose a weight of about 800 gms was attached to the tow line at a distance of 1 meter from the net. Thus, provided the tow line of 20 meters is so kept as to make an angle of 30° with the horizon, the net will sweep the layer of 10 meters depth. Of course the angle of 30° is achieved by regulating the speed of the boat.

As for the above horizontal collection it was at first anticipated that its result might be irregular and erratic. On the contrary, it was found that its results show values which paralleled closely those of the vertical collection, though reading of the volume naturally differ.

Other than the above ones a collection using a plankton net of coarser mesh, (say Müllergaze No. 3) was also carried out, in case when the macroplankton was surmised to abound.

(4) VOLUME MEASURE. The plankton collected was fixed in 5% formalin and was settled for 24 hours in a graduated cylinder, then the volume was read in terms of cc. When the volume of plankton was too abundant the estimation was made on an aliquot volume of a collection.

(B) Results.

(1) General Trend of the Seasonal Change of Plankton

The plankton of Mutsu Bay shows a regular seasonal change from year to year. At the beginning of the year, during January and February, the quantity and the species of plankton are meagre. However, during March and April, the quantity of plankton increases rapidly due to the vernal vegetation of plankton Diatoms, though in this case the number of species does not necessarily increase. This is because the increase in this case is caused exclusively by a few species of Chaetoceros. During and after May until mid-June the Diatoms decline and boreal species of the zooplankton predominate.

The immigration of boreal plankton into Mutsu Bay in this season is one of the most notable phenomena in the course of seasonal change. This boreal plankton is surmised to be derived from the cold water zone which is present in the northern part of the Japan Sea, and approaches the Tsugaru Strait during this season. The grade of the approach of this cold water probably differs according to the influence of the west wind which prevails more or less randomly at that season. Consequently it follows that the occurrence of boreal plankton in Mutsu Bay is not so regular as that of tropical plankton which appears in autumn. Nevertheless it must also be borne in mind that the above said boreal plankton is of great importance as its quantity is immense if it appears at all. As to the details of boreal plankton and its immigration in Mutsu Bay the readers are referred to the author's earlier study (Kokubo, 1950).

From June on the plankton gradually changes into summer association, its culmination being shown in late August. The summer plankton consists of local species which propagate at any time, provided only that the temperature increases, it being virtually coastal in origin. Those species must be clearly distinguished from tropical species, which in our locality come migrating a great distance from tropical seas. Therefore the occurrence and abundance of these forms in

Mutsu Bay signifies the fluctuation of the influx of tropical water. This greatly enhances the interest of the seasonal change of plankton in Mutsu Bay.

From early September to December the temperature of the water decreases markedly. During this changing condition of autumn there occur two remarkable changes in plankton, viz. appearance of tropical plankton and the autumnal flourishing of Diatoms. These two phenomena are essentially different in their nature. The former is due to the migration of tropical species from south: the latter is caused by the vegetation of the endemic Diatoms. But both phenomena usually overlap in time.

The tropical plankton appearing during this season is well represented by Copepoda and Diatoms. However, the number and species of these organisms vary from year to year, probably because the strength of the Tsushima Current, which brings the tropical species in, fluctuates year by year. The Tsushima Current, a prominent warm current which flows northwards along the Japan Sea coast of the mainland of Japan, has its origin in the eastern seas of Formosa and the Philippine Islands where the North Equatorial Current prevails. As to why these tropical species appear only in autumn when the water temperature is decreasing: the warm current which flows into the Japan Sea through the Korea Strait constantly moves northwards with its immigrant plankton, but as it proceeds farther north these organisms gradually perish because the temperature decreases. The northernmost limit of its distribution may differ according to the season, the furthest distribution being attained in autumn when the strength of the warm current is probably at its height and the temperature of the northern seas is still warm enough.

In so far as the observation on the distribution of tropical Copepoda, Diatoms and Radiolaria is concerned the northernmost limit of these organisms seems to be not much further than the latitude of Tsugaru Strait. According to Sato's (1913) study on Copepods, Akatsuka's (1914) study on pelagic Diatoms, Motoda's (1950) study on the summer plankton, Iizuka's (1950) study on Ceratium, all of these being the plankton of the western sea area of Hokkaidô, the influence of warm current on the west coast of south Hokkaidô, is very weak. Such a decline of the Tsushima Current must be the result of cooling of the water by the northern climate, but a more pronounced cause is the outflow of this current from the Japan Sea to the Pacific Ocean passing through the Tsugaru Strait. Because of this outflow of current to the Pacific Ocean the greater part of the strength of the Tsushima Current is likely to be lost before it reaches the west coast of Hokkaidô, naturally resulting in the limited distribution of tropical plankton in the above locality. The autumnal flourishing of Diatoms usually occurs during the period from mid-September to late November. Its magnitude of vegetation is usually inferior to the vernal vegetation, though the opposite is sometimes the case. Sometimes the vegetation occurs in early September while in another case

it occurs delayed until November or even in December. Such a shift of season is nothing but that the early vegetation is caused by the warm water species while the later vegetation is caused by the winter species. It happens also that a mixed vegetation of warm and cold water species is sometimes, though rarely, found. At all events the autumnal vegetation of Diatoms is remarkable because it occurs regularly and plays a pronounced role in plankton phenomena at the end of the year.

Uda (1931) studied the velocity of the Tsushima Current and found that the water mass which enters the Japan Sea through the Tsushima Strait takes about six months to reach the Tsugaru Strait. This speed is surprisingly slow, but if it is taken as conclusive the tropical plankton which occurs in Mutsu Bay in October must have been in the Tsushima Strait in March, when the water temperature shows about 13,0°C. This temperature is equal to the mean temperature of November in Mutsu Bay, being much lower than the mean temperature of October (17,5°C), when the occurrence of Tropical plankton culminates. In Mutsu Bay it is evident that the tropical plankton rapidly declines from November afterwards. Therefore it is obvious that the tropical plankton which arrives at Mutsu Bay has met with a critical temperature condition when passing through the Tsushima Strait. According to Uda (1931) the travelling of a water mass, with high salinity, in the Japan Sea was previously reported by Marukawa (1926), the matter then had been highly consistent. From these facts it is reasonably thought that it is this water mass which conveys the tropical plankton so great a distance as to the Tsugaru Strait, and consequently to Mutsu Bay.

(2) The Seasonal and Annual Change of Quantity of Plankton during the Four Years of 1947-1950.

The results obtained during 1947-1950 are shown in Table I and in Fig. 1 annexed. Among the figures given in the table the values given in the column 'Mean' show the average of 0 m and 10 m collections. From this table it will be seen that in 1947 the vernal increase was found in March, and that this increase was mainly due to the vegetation of Diatoms e.g. *Nitzschia seriata*, *Chaetoceros debilis*, and also the propagation of *Noctiluca scintillans*. The plankton, which were relatively low in quantity during the period from April to July, began to increase from August on. This increase was most marked from early September to early October. Then after decreasing slightly it again showed a marked increase from early November till early December. The earlier increase was due to the vegetation of *Chaetoceros distans*, a warm water species. The later increase, from November on was due to *Chaetoceros subsecundus*, a temperate species. These two increases can be called together an autumnal increase, though the casual species differ.

From Fig. 1 and Table I one will note that in this year the autumnal increase

is by far more prominent than the vernal increase, while in the three following years the opposite is the case.

In 1948 the quantity of plankton during the spring was apparently more rich than in 1947. But a distinct increase which can be regarded as vernal flourishing was not observed till Apr. 1st when a great increase occurred, an increase so marked as had not been observed in 1947. This increase, however, rapidly declined, and during the period from mid-May till the end of the year four periods of erratic increase were observed instead of a single increase in autumn. Such a mode of change may not be rare; such cases have also been observed in 1931 and 1932 (Kokubo, 1934). Vernal increase in 1947 was caused by the vegetation of *Chaetoceros affinis*. The next increase (second peak in Fig. 1) was found on May 18th, its cause being combined vegetation of *Chaetoceros affinis* and *Ch. decipiens*. The third peak of August in Fig. 1 was due to the increase of *Chaetoceros distans*, a warm water species. Both the fourth and fifth peaks, of November and December, were caused separately by *Chaetoceros setoensis*, a warm water species which is a rather uncommon species, felt to be strange because of its newness. Such a development of this species may be attributed to the unusually high temperature of the water during this year.

In 1949 the vernal increase was found early in February because of the vegetation of *Chaetoceros affinis*. Although in Fig. 1 the peak representing this increase was not shown because of the failure of vertical collection, the curve of horizontal collection indicates this increase. This increase declined rapidly, reaching its minimum in May. After this the quantity gradually increased and two maximums were observed in September and in December. In these cases too, the earlier increase owed its cause to the vegetation of *Chaetoceros distans*, i.e. a warm water species, and later one was due to the vegetation of *Chaetoceros constrictus*, a cold water species.

In 1950 the vernal flourishing was observed twice, the earlier one in March and later one in April. The earlier vegetation was due to the development of *Chaetoceros debilis*, a distinct cold water species, and the magnitude of this vegetation was greatest in this year. The later vegetation was due to the multiplication of *Nitzschia seriata*, a temperate species. This vegetation rapidly declined and attained a minimum in June. After this decrease an apparent increase was seen in July, due to the vegetation of *Chaetoceros distans*. With the advance of the season the autumnal increase was twice found, separately, in September and in October, both being due to the vegetation of *Chaetoceros distans*. In short the seasonal change in 1950 was fairly typical, the vernal increase being by far greater than the autumnal increase.

Passing on to the problem of the quantity of plankton it can be said that the calculation of actual volume of the plankton from the figures of vertical collection is a useful method. The highest value of vertical collection during the four years

of 1947-1950 was 265 cc, observed on April 1st, 1948. Therefore if the filtration coefficient was assumed to be 1, the quantity of plankton per cubic meter of water will be calculated as follows: $\frac{265}{0.75 \times 30} = 11.7$, where 265 cc=actual quantity collected, 0.75 m²=area of the entrance of the net, 30=distans towed. The quantity of plankton contained per cubic meter of water was found to be 11.7 cc. In contrast to this the result of the earlier investigation (Kokubo, 1931a) made in 1931 at the same station showed this value to be 727 cc. That such a marked difference may not be due to the yearly fluctuation of the maximum value can be inferred from the fact that the value 11.7cc is the highest value of the observation of four years. Therefore such a low value of the present study should be attributed to the presence of a high filtration coefficient which was supposed to be a value larger than 3 in the preceding comments.

(3) The Seasonal and Annual Change of the Plankton Association.

In the preceding pages the seasonal and annual changes were stated in relation to the quantity of plankton. Such changes, however, not only occur in the quantity but also occur in the quality, i.e. association constitution of the plankton. As is well known the association of plankton is very complex, often consisting of hundreds of species. Therefore the present description will be based on some limited groups of phyto- and zooplankton, devoting particular attention to the groups which are either directly related to the production of the sea or are significant for inferring the biological conditions of the sea. Looking through the annexed tables (Table II, III) it will be found that such species of phytoplankton are the several species of *Chaetoceros*, *Nitzschia*, *Skeletonema*, *Asterionella*, *Rhizosolenia*, *Bacteriastrum* etc, and those of the zooplankton are the several genera of *Copepoda*, *Copepoda* and *Radiolaria*. In the following pages the seasonal change of these groups in 1950 will be stated, and annual or yearly change of these groups will be separately stated in connection with the years 1948-1950. According to the temperature observations which have been made three times every day at our station's pier 1950 was a very warm year, the annual average being 13.9°C. This temperature was much higher than that of 1948 (13°C) and also than the average year (13.4°C). But it was slightly lower than 14°C of 1948. a year extraordinarily warm in recent years. Therefore the seasonal change stated below will be taken as representing an example of a warm year.

(a) SEASONAL CHANGE IN 1950.

During January and February of this year the plankton was dominated by typical winter species, the Diatom being represented by *Chaetoceros debilis*, *Ch. socialis* and the Copepoda represented by *Centropages abdominalis* and *Paracalanus parvus*. Other than the above species *Asterionella japonica* and *Rhizosolenia imbricata*, the temperate cold species, showed a moderate ab-

undance. It was also notable that in mid-February such warm water species as *Ceratium candelabrum* and *Stychnolonche* sp. were yet found as survivors of the former year.

The above plankton began to show a gradual change from early March, though a few species of Copepoda above seen remained almost unchanged, some species of Diatoms such as *Chaetoceros subsecundus*, *Ch. compressus*, *Nitzschia seriata*, *Coscinodiscus Wailesii* showed a slight but steady increase. Of these species the increase of *Nitzschia seriata* was very notable for the reason that this increase was the first sign of a marked increase of this species from late March on. Concerning Diatoms it was also notable that in spite of a remarkable increase of volume by late March the number of species markedly decreased. Such a decrease of Diatom species is a common phenomenon of this season from year to year, being due to the disappearance of warm or temperate species on account of the minimum temperature of the year. The minimum temperature of the year usually occurs during the period from late February to early March and ranges around 5.0°C, under which the winter species such as *Chaetoceros debilis* and *Ch. socialis* show the spring flourishing. Such a relation is also the case with zooplankton, showing that the last survivors of warm water species, e.g. *Paracalanus aculeatus*, *Stychnolonche* sp., and *Ceratium candelabrum* perish, and *Centropages*, a typical winter Copepoda, and *Sagitta crassa* increase. *Noctiluca scintillans* which represents the spring plankton also commenced to increase in late March.

The water temperature, which fell to the minimum in early March, began to increase from late March coinciding with the increase of *Nitzschia seriata* and *Centropages abdominalis*. At the same time a marked decrease of *Chaetoceros debilis* and *Ch. socialis*, on account of the increase of temperature, also occurred. *Nitzschia seriata* is a temperate cold species which usually vegetates preceding the temperate species such as *Chaetoceros decipiens*, *Ch. affinis*. But the increase of *Nitz. seriata* in this case is by no means so marked that it increases the total volume of the plankton. Therefore the total volume, which decreased with the decline of spring vegetation, viz., decrease of *Chaetoceros debilis* and *Ch. socialis*, was left in a very meagre state.

From the beginning of May to the end of June a gradual increase of temperature continued steadily, the mean temperature of the two months being respectively 13.7°C and 16.7°C. During this time the vegetation of Diatoms was almost suppressed except *Nitzschia seriata* which continued slight but regular multiplication. Paralleled with the volume decrease of Diatoms the decrease of the number of species also occurred from late April till early June when the Diatoms as well as Copepoda became almost nothing. How severe this decrease was can be recognized by the fact that the *Chaetoceros*, which often occurs in more than 20 species, diminished to only 4 species, the Diatoms becoming only 9 species in all. Consequently June was the most barren month of the plankton of this year. The

only increase seen in this month was that of *Noctiluca scintillans* which continued till the end of July. The appearance of *Pseudocalanus elongatus* since late April was more or less noteworthy as it appears in abundance in May according to the yearly condition. According to yearly circumstances April is often enlivened by boreal immigrants such as *Calanus plumchrus*, *Calanus cristatus*, *Sagitta elegans*, each of which is an important food of fishes. As to the reason why none of these species appeared this time the author reminds the reader of the unusual warm temperature of this year, already mentioned.

In short, June was the month of least plankton, the cause probably being the want of nutrition which was not yet recovered from the decaying plankton. The decrease of Diatoms in this season is an inevitable consequence of the regular change of plankton, but it is also probable that the decrease may be hastened by the appearance of *Noctiluca scintillans*, a voracious feeder on Diatoms.

The plankton change so far mentioned is not at all apart from winter or spring condition. In early July, however, an incipient sign of changing into summer plankton has been observed. The first indication of this was the appearance of *Centropages Kröyeri* and *Doliolum nationalis*. Of these species *Centropages Kröyeri* is a warm water species appearing in place of *Centropages abdominalis* which is a distinct winter species. The appearance of *Doliolum nationalis* in the group also reflected the warm water condition. Advancing to late July the summer condition was distinctly demonstrated by the vegetation of *Chaetoceros distans*, *Ch. didymus*, *Ch. affinis*, the first one being a true summer species which continued its flourishing till the early October of this year. The occurrence of *Öikopleura fusiformis* instead of *Oik. dioica*, and appearance of a species of Radiolaria markedly manifested the warm water condition.

At the beginning of July *Chaetoceros debilis* showed a little vegetation, slightly increasing the total volume of plankton, but from then till late August all plankton showed a meagre state. The temperature of the water during July was extraordinarily high, so high as to exceed the water temperature of 1948, a warmest year. The highest temperature observed on July 23rd was 27.8°C and the monthly average was 21.0°C. These high temperatures probably stimulated the Diatoms to vegetate, thus giving rise to the long flourishing of *Chaetoceros distans*, for this species is subtropical in nature rather than being a warm temperate species. The temperature of water during August was little lower than that of 1948, with a mean value of 25.7°C, a value lower by 3°C than in 1948. During August no marked change was observed in plankton except that *Chaetoceros distans* vegetated more and more and also that the species of *Chaetoceros* which decreased to only four species now increased to 14 species by early August. The water temperature which increased to its maximum in August commenced a gradual decrease from early September afterwards. 23.7°C which was observed on the 1st gradually decreased to 19.7°C by the 30th, showing a mean temperature

of 23.5°C, i.e. a more or less high value as compared with the average year (21.9°C).

In studying the plankton of Mutsu Bay September is the month of a great interest because in this month there occur two distinct phenomena. The first of these is the autumnal increase of Diatoms, and the other is the appearance of the forerunner of immigrant plankton from the tropics.

The plankton which had been in a meagre state since early April suddenly developed a rich flora on Sept. 7th. This increase was the autumnal maximum of Diatoms and was caused by the vegetation of *Chaetoceros distans*, assisted by *Ch. curvisetus* and *Ch. didymus*, and accompanied by such warm water species as *Rhizosolenia cylindrus*, *Hemidiscus cuneiformis*, *Climacodium Frauenfeldianum*, and *Cerataulina Bergonii*. In late September some more tropical species viz. *Ch. rostratus* and *Ch. coarctatus* appeared. In zooplankton too there were found many warm water Copepoda, e.g. *Paracalanus aculeatus*, *Centropages yamadai*, *Corycaeus curtus* and *Eutерpe acutifrons*. Moreover *Evadne tergestina*, *Fritillaria borealis* f. *sargassi* and *Ceratocorys horrida* also represented the warm water. Of these warm water plankton the Diatoms which can be considered as tropical immigrants are *Rhizosolenia cylindrus*, *Ch. rostratus*, *Hemidiscus cuneiformis* and *Climacodium Frauenfeldianum*, such zooplankton as *Paracalanus aculeatus*, *Fritillaria borealis* f. *sargassi* and *Ceratocorys horrida* likewise representing the tropical immigrants.

The tropical feature of plankton which was first shown in late September became more and more distinct from early October on. On Sept. 1st were found three tropical immigrants, i.e. *Chaetoceros costatus*, *Ch. anastomosans*, and *Hemidiscus cuneiformis*, each of which is a true tropical species. On Sept. 15th there was found a distinct tropical immigrant, *Calocalanus plumulosus*, which in Mutsu Bay obviously demonstrates the arrival of tropical water from the south. The Diatoms also showed a marked tropical feature by the appearance of *Chaetoceros diversus*, *Ch. paradoxum*, *Ch. denticulatus* and *Bacteriastrum comosum*. Of these four species *Ch. diversus* is a typical immigrant from the tropics. On the other hand the number of species of Diatoms increased up to 62, of which *Chaetoceros* comprised 29.

During October the water temperature shows more or less rapid decrease. In 1950 the water temperature of Oct. 1st was 10.9°C, decreasing to 14.2°C by the end of the month. The mean temperature of this month was 17.4°C, a temperature which is probably much lower than the critical temperature of tropical organisms.

From what has been so far mentioned it will be seen that in October, especially in its latter half, the plankton of Mutsu Bay is enriched with tropical species. As these tropical forms must be brought by the Tsushima Current from the south it can be said that during autumn the strength of this current is at its height, and that its strength in Mutsu Bay might be estimated by the abundance of the above plankton.

The warm water plankton which attained its maximum in late October passed its culmination by early November, though some tropical forms still remained and some new immigrants (*Ch. messanensis*, *Ch. pseudocurvisetus*) were yet arriving. Such a change is indicated by the fact that *Ch. distans*, which had been taking a leading part, by early October was replaced by *Ch. decipiens*, a temperate species. Also, a cold water species, *Ch. socialis*, appeared in late November. In early December, when the water temperature ranged around 10.0°C, the plankton was likewise outnumbered by *Ch. decipiens*, but the tendency of winter species such as *Ch. debilis* and *Ch. socialis* to increase became marked. The survivors of tropical species in this season were *Ch. messanensis*, *Hemidiscus cuneiformis*, *Ceratium platycorne*, and *C. pentagonum*. By Sept. 15th the preponderance of the winter species became more and more distinct, but the hindermost representatives of warm current, e.g. *Ch. messanensis*, *Ceratium candelabrum* still survived.

Taken altogether, the seasonal changes of plankton during 1950 can be summarized as follows. January and February were the months in which the winter species (*Ch. debilis*, *Ch. socialis*, *Centropages abdominalis*) were in readiness to increase. During March a vernal maximum of Diatoms due to an outburst of vegetation of *Ch. debilis* and *Ch. socialis* was observed. This vegetation was followed by a rapid decrease from early April, in concomitance with the decrease of species. At the beginning of June the plankton decreased to the minimum of the year in number of species as well as in quantity. In early July the first sign of the occurrence of summer species was observed. During autumn two distinct phenomena occurred in turn, the one being the autumnal Diatom maximum and the other being the immigration of tropical species. The former occurred in early September, caused by the increase of *Ch. distans*, its abundance being not so surprising as that of the spring. The latter occurred from late September on and was shown by the appearance of tropical species of Copepoda and Diatoms. These phenomena almost terminated by mid-November, and from then on the plankton gradually changed into winter form.

(b) THE YEARLY CHANGE DURING THE PERIOD FROM 1947 to 1950.

The change of the plankton stated here is concerning the four year period of 1947-1950. The yearly change of plankton (inter-yearly change, not intra-yearly change) in a definite area seems to be repeated following a definite course. Therefore the changes observed during the above four years can be considered to represent the state of changes in an indefinite period, so far as no remarkable change occurs in environmental conditions. In other words such changes as are described here will be repeated from year to year over a long period. But this is likely to be the case only with so-called 'Net Plankton' which is relatively homogeneous in constitution and has the tendency of being firm and steady in the seasonal as well as the regional distribution. As to the megaloplankton, some

of which is a random frequenter of Mutsu Bay, the problem becomes quite different, the regularity of their occurrence being hardly possible to assign to a definite period. This is probably because their period of occurrence is, if there are present, longer than one year, sometimes spreading over a series of years, and hence they often escape our attention. Examples of this kind in Mutsu Bay are such as the large medusae, e.g. *Cyanea capillata*, *Rhopilema esculenta*, *Charybdea rastonii*, etc.; and *Salpa vagina*, a large tropical species, etc. Though the occurrence of these species must be one of the chief concerns of the author the subject of the present study is confined to the net plankton, so that the information about the periodical change of the above species is reserved for another occasion. Therefore in the following pages the yearly change will be discussed by picking out some dominating species of the net plankton of a season.

It can generally be accepted that the cause of the yearly change of the plankton has close bearing on the temperature of the water. Therefore in describing the yearly change, each of the four years will be compared with others in connection with the water temperature. Moreover for the sake of convenience the description will be made dividing each year in four quarters.

FIRST QUARTER. The first quarter of the year, viz. from January to March, is the period in which the change of temperature is relatively small. The mean temperatures (mean value of 25 years, 1914–1950 except 1926) of January, February and March are respectively 5.7°C, 4.5°C and 5.6°C. The monthly mean of January, February and March of the four successive years is tabulated as follows.

	1947	1948	1949	1950
January	5.6°C	4.9°C	7.4°C	5.5°C
February	4.7°C	3.9°C	4.6°C	5.8°C
March	5.0°C	5.7°C	6.1°C	6.0°C

The lowest temperature of the year occurs in late February, its value in 1947, 1948, 1949 and 1950 being respectively 3.0°C, 3.2°C, 6.0°C and 5.1°C. The change of water temperature due to year, i.e. yearly difference, is relatively large, especially in January and February.

In each of the above four years the leading species of the phytoplankton in January were *Ch. socialis* and *Ch. debilis*. This was a well-agreed fact through this period, suggesting no yearly change of plankton during January. The species second to these species varied according to year, being in 1947 *Ch. decipiens*, *Biddulphia sinensis*, and *Coscinodiscus concinnus*, in 1948 *Ch. affinis*, in 1949 *Ch. constrictus*, in 1950 *Asterionella japonica* and *Rhiz. imbricata*. On the other hand it is worth a little attention that in 1947 *Ch. debilis* and *Ch. socialis* were relatively scarce, and instead *Noctiluca* was found in plenty. This probably means that

in January 1947 the plankton of last autumn survived yet in quantities. The zooplankton dominating this season were *Centropages abdominalis*, *Paracalanus pavus*, *Sagitta crassa* f. *naikaiensis* and *Noctiluca scintillans*, of which the former two species were scarce in 1947-1948 and the latter one was scarce in 1949-1950.

In February the leading species of Diatoms were just the same as in January, dominated by *Ch. debilis* and *Ch. socialis*. Differences of these species due to year were almost nothing except in the year 1947 when *Ch. socialis* was slightly less than in other years. In other species of Diatoms some notable differences were found, e.g. in 1949 the leading species were *Ch. affinis* and *Ch. compressus*, and *Ch. radicans* also occurred in abundance, such being not the case with any of the other three years. Among the species which appeared in second abundance *Nitzschia seriata* showed an even occurrence, though in 1950 only it was very scarce. The other species which showed the second abundance varied according to year. For instance *Skeletonema costatum* which occurred in moderate abundance was not found in other years in any appreciable quantity. Other than the above species *Ch. constrictus* appeared only in 1949 in moderate abundance, while *Rhiz. acuminata*, *Asterionella japonica* and *Biddulphia sinensis* crowded only 1950. As for the zooplankton the main species dominating this season were *Centropages abdominalis*, *Paracalanus pavus* and *Pseudocalanus elongatus*, though in 1949 these species were very scarce.

Of the changes above mentioned the species of Diatoms which appeared in 1949 in abundance is noteworthy for the fact that all of them except *Ch. debilis*, *Ch. socialis* and *Ch. constrictus* are of temperate nature, such species being ordinarily found from April afterwards. The occurrence of these species in the coldest season of the year may be accounted for as due to the unusually warm temperature of this month in 1949.

During March the leading species varies from year to year. For instance in 1947 the species of highest abundance was *Ch. debilis*, in 1948 *Ch. constrictus* and *Ch. affinis*, and in 1949 *Nitzschia seriata* and *Coscinodiscus Wailesii*, while in 1950 it was again *Ch. debilis*. Such changes were much more distinct as compared with these in the preceding two months. This is probably due to the fact that March is a critical month, its biological conditions being on the verge of change from winter to spring. These conditions, however, cannot be explained from the single cause of temperature. This can be understood by the fact that at the end of March the Diatoms often show an outbursting vegetation before the water temperature commences to increase.

Summing up the above results it can be said that during the first quarter of the year the yearly change is so small that it can be called a constant period. The first quarter of each year of 1947-1949 was represented by *Ch. debilis* and *Ch. socialis*, which occurred invariably through this period of four years. The constancy of these species is particularly distinct during February, while in January

and March the occurrence of these species is slightly less constant. This is because in January there remains the effect of autumn plankton whose influence varies with the year, and in March there occurs the effect of spring plankton whose influence varies also with year.

SECOND QUARTER. The second quarter is the period ranging from April to June. This period is the season in which the water temperature increases steadily from early April till late June. The mean temperatures (mean value of 25 years) of April, May and June are respectively 8.6°C, 12.1°C and 16.2°C. It is a characteristic of the temperature of this season that in each of three months the temperature greatly varies with year. The monthly means of April, May and June of the four successive years are tabulated as follows.

	1947	1948	1949	1950
April	7.7°C	9.9°C	7.8°C	10.0°C
May	11.6°C	13.4°C	12.5°C	13.7°C
June	14.3°C	16.9°C	14.7°C	16.7°C

In April in 1947 the species which dominated the plankton of this period was *Noctiluca scintillans*, the second to this being *Nitzschia seriata*. In 1948 the *Noctiluca* wholly disappeared, the highest abundance being shown by *Ch. affinis* which was almost absent in the preceding year. The second abundance was represented by *Nitz. seriata*, *Ch. compressus*, and *Rhiz. hebetata f. semispina* etc. In 1949 *Ch. affinis*, which dominated the preceding year, declined, and the highest abundance was shown by *Nitz. seriata* and *Noctiluca scintillans*. In 1950 the leading species were *Ch. debilis* and *Nitz. seriata*, the species second to this being *Ch. constrictus*, *Ch. decipiens* and *Noctiluca scintillans*. Thus, in April the leading species varied from year to year, though *Nitz. seriata* and *Noctiluca scintillans* showed the tendency of appearing every year. The abundance of *Ch. affinis* in April 1948 may be considered associated with the warm temperature of that month.

In May 1947, the coldest year of the four years, the Diatoms were almost lacking the highest and the next abundance being respectively represented by *Centropages abdominalis* and *Paracalanus parvus*. In the next year, 1948, the above two species disappeared, and the leading part was taken by *Ch. affinis* and *Pseudocalanus elongatus*, the second abundance being shown by *Sagitta crassa*. In 1949 the condition again changed and the species which dominated the preceding year disappeared, the leading part being taken by *Centropages abdominalis* and *Noctiluca scintillans*. In 1950 the highest abundance was represented by *Nitzschia seriata* and *Centropages abdominalis*, the second and the third abundance being respectively shown by *Ch. debilis* and *Noctiluca scintillans*.

From the above it will be seen that the yearly change of the dominant species in May is very distinct, as is the case in April. But taken altogether it can also be said that in this month there is a tendency that the highest and the

second abundance are apt to be represented either by *Nitzschia seriata* or *Centropages abdominalis*, and in some cases by *Noctiluca scintillans*.

In June 1947 *Ch. decipiens* topped the abundance figures, the next being *Noctiluca scintillans*. In June 1948 *Ch. affinis* showed the highest abundance in place of *Ch. decipiens*, which was the leading species of the preceding year. The species of the second abundance in this year were *Nitzschia seriata*, *Ch. decipiens*, and *Ch. distans*. In 1949 the species dominating this month was *Nitzschia seriata*, the second and the third to this being *Ch. affinis* and *Ch. distans*. Lastly, in 1950 *Nitzschia seriata*, which was the leading species in the preceding year, was replaced by *Noctiluca scintillans*. In short in June too the yearly change of plankton is remarkable, the highest abundance being represented by any one or two of *Ch. decipiens*, *Ch. affinis*, *Nitzschia seriata*, or *Noctiluca scintillans*.

Summerising the change of the plankton above mentioned, it is evident that during the second quarter of the year the change of plankton due to year is very remarkable. The cause of such notable change might probably be that the change of temperature during this season varies to a great extent from year to year. It must be borne in mind that during April and May rivers empty thawing water into Mutsu Bay in different quantities every year. This may give rise to the yearly change of the plankton as the freshet highly influences the environmental conditions of the organisms.

THIRD QUARTER. The third quarter covers the period from July to September. The characteristics of the water temperatures of this season are that during July the temperature, which had been increasing since April, continues its increase till late July. During August the temperature becomes stable, showing the warmest condition of the year, the highest temperature usually being found mostly around the 15th of the month. From this afterwards through September the temperature gradually decreases. The mean temperatures (mean value of 25 year) of July, August and September are respectively 20.7°C, 23.9°C, and 21.9°C. The monthly means of July, August and September of the four successive years are tabulated as follows.

	1947	1948	1949	1950
July	21.1°C	21.4°C	16.0°C	21.6°C
August	24.2°C (25.6°C 15th)	26.1°C (28.0°C 17th)	23.1°C (26.6°C 14th)	25.7°C (27.8°C 17th)
September	21.3°C	22.4°C	22.3°C	23.5°C

The temperature and dates shown parenthesized in the above table denote the highest temperature of August and its date of observation.

As has just been mentioned the yearly change of the second quarter was very marked. This tendency is still held in the early part, viz. during July of

the third quarter. During July in 1947 the first and second abundance were represented by *Dactyliosolen tenuis* and *Ch. radicans* respectively, while in 1948 these were respectively replaced by *Ch. affinis* and *Ch. distans*; but in 1949 these were represented by *Ch. affinis*, *Ch. radicans*, and *Nitzschia seriata*. Unlike these three years, in July 1950 the first and the second abundance were represented by *Noctiluca scintillans* and *Ch. distans* respectively. Thus it is to be noted that during July the yearly change is very marked. Such a changeable tendency of this season is probably due to the fact that yearly fluctuation of oceanographic conditions during July is also very marked.

With the advance of the season the above tendency undergoes a change. During August the first and the second abundance are represented by *Ch. distans* and *Ch. affinis*, no change being shown through the four years. There is, however, an exceptional occurrence of *Noctiluca scintillans* which is, by nature, a species apt to show erratic occurrence according to circumstance. The cause of the disappearance of yearly change in August should be ascribed to the oceanographic conditions whose yearly fluctuation also became less as compared with that in preceding months.

The disappearance of yearly change observed in August became more and more accentuated in September, thus producing a stable period, the first abundance being represented by *Ch. distans*, which continues its predominance from early August every year. The second abundance in September varies more or less with year, being represented by *Ch. affinis* in 1947, by *Paracalanus* in 1948, by *Ch. didymus* in 1949, and by *Ch. curvisetus* in 1950. In short *Ch. distans* predominated consistently among the plankton of August and September through the four years of 1947-1950.

FOURTH QUARTER. This is the period covering the three months from October to December, in which the water temperature has a decreasing tendency. The rate of decrease in September and October is gradual but becomes rapid from early November afterwards. It is notable that in the first two months the yearly fluctuations of water temperature are distinctly less than those of the second quarter in which the water temperature is increasing. This may possibly mean that during the second quarter the water temperature is left to the influence of air temperature in that season. In the fourth quarter, however, there is another factor influencing the water temperature, viz. the influx of ocean current which flows in from the Tsugaru Strait, this current being of constant nature in temperature. The mean temperatures (mean value of 25 years) of

	1947	1948	1949	1950
October	17.3°C	18.7°C	18.9°C	17.4°C
November	11.0°C	12.7°C	11.9°C	12.8°C
December	5.4°C	9.3°C	7.9°C	8.2°C

September, October and November are 21.9°C, 17.7°C and 12.7°C respectively, the lowest temperatures observed at the end of each month being 2.0°C, 15.4°C and 10.2°C respectively.

It was noted in the preceding page that during the latter two thirds of the third quarter almost no yearly change was observed. This tendency has been held till October, the dominant species of four years being *Ch. distans*. The species of second abundance, however, varies with the year as has been the case with September.

Entering November the constancy of plankton above mentioned was discontinued, causing marked change from year to year. The plankton which predominated in November of the four years varied in this order : *Ch. subsecundus* in 1947, *Ch. setoensis* in 1948, *Ch. constrictus* in 1949, *Ch. decipiens* and *Skeltonema costatum* in 1950.

The yearly change so far mentioned is concerned mainly with the endemic plankton, whereas there occurs in October the tropical plankton which is brought by oceanic current from the south. Differing from the endemic plankton this immigrant plankton shows but little change from year to year, at least in its constituents, because of its being oceanic plankton. The yearly change, if any, in this plankton bears a quite different meaning from that of endemic plankton. Namely the yearly change of immigrant plankton signifies the yearly fluctuation of oceanic current, while that of the endemic plankton merely denotes the change of the environmental conditions of the specific region.

The yearly change which became very marked in early November held the same tendency till the end of December, the change of dominant species according year being as follows : *Ch. subsecundus* and *Ch. socialis* in 1947, *Ch. setoensis* in 1948, *Ch. constrictus* in 1949, and *Ch. decipiens* in 1950. Thus it has been made clear that in the first month of the fourth quarter no yearly change was recognized, but in the latter two months the yearly change was prominent.

Summing up the above results the following conclusions have been deduced.

- (1) In Mutsu Bay there are four periods in relation to the yearly change of the plankton.
- (2) The first period (Constant period) covers the period from January to February, in which similar plankton occur from year to year, thus showing no yearly change. The constancy of plankton in this period is indicated by the invariable vegetation of *Ch. debilis* and *Ch. socialis* every year.
- (3) The second period (Varying period) covers the period from March to July, in which different plankton appears from year to year, thus showing distinct yearly change. The plankton which cause such change are *Ch. affinis*, *Ch. decipiens*, *Ch. debilis*, *Ch. constrictus*, *Ch. radicans*, *Dactyliosolen tenuis*, *Nitzschia seriata*, *Centropages abdominalis*, and *Noctiluca scintillans*.

lans.

- (4) The third period (Constant period) covers the period from August to October, in which similar plankton occur from year to year, thus showing no yearly change. The constancy of plankton in this period is indicated by the constant vegetation of *Ch. distans* every year.
- (5) The fourth period (Varying period) covers the period from November to December, in which different plankton appears from year to year, thus showing distinct yearly change. The plankton which cause such change are *Ch. subsecundus*, *Ch. setoensis*, *Ch. constrictus*, *Ch. decipiens*, and *Skeletonema costatum*.

CHAPTER II, General Survey of the Plankton Organisms.

Needless to say the plankton exist in myriads species of plant and animal life. Therefore to study properly the composition of the plankton one must inquire into every form of pelagic life which occur in all classes of the plant and animal kingdom. At the same time, however, it is also true that when the aim of the study is centered on some practical purpose say fishery investigation, the above idea is not always the case, because in most practical plankton study the subject of the investigation is definitely "Net plankton" which does not necessarily include any novel species of large medusae. Therefore it may not be too much to say that the study of the net plankton can never be the study of organisms other than the Diatoms and Copepods. If the Dinoflagellata, Copelata and Chaetognatha are added to the above two groups the net plankton well represents the whole plankton in practical sense. Indeed in any time and region of the world there may be no collection in which no Diatoms or Copepoda are contained. This is the reason why ignorance of the above two groups is inexcusable in any one who wants to study the practical plankton. Especially when the object of an investigation is a quantitative finding the final analysis must be made from the study of the above two groups.

In the present investigation too, importance has been attached to the Diatoms and Copepods as the bulk of the plankton consisted of these two groups. The importance of these two group is not only because of its quantity but also that in these groups there are many species which are the so-called "Indicators" of ocean current and become a strong clue in tracing the movement of water masses. In the present study the phytoplankton was exclusively represented by the Diatoms, its species numbering 129. The zooplankton is represented by Copepods its species numbering 37. In these species of two groups are included many "indicator species" which are indicative of warm or cold current.

In the study of plankton a matter of great concern is the naming of the species. Even though the investigator is well trained the difficulty of identification can not always be overcome. Especially when the study is concerned with ecology

the authentic identification of every species is extremely hard, if not impossible, because it is usually the case that numerical treatment of extensive collections is hoped for to proceed acceptably. In the present investigation, too, the author is not convinced that the infallible naming of species is attained, but reservedly it can be said that he nears exactitude.

(A) Diatoms.

Among the chief constituents of the pelagic community in Mutsu Bay the Diatoms are the first in numerical as well as species abundance. Concerning the abundance of plankton Diatoms off the Japanese coast the author (Kokubo 1939) made a study in which it was reported that of the sixteen representative stations along the coast of Japan, Mutsu Bay is the fifth in order of Diatom abundance, its annual average of the cells per litre of water being 37002. In another study by the same author (Kokubo, 1934) the abundance was measured in volume, it being found that this ranged from the minimum of 15.9 cc to the maximum of 1672 cc, with the average of 229 cc per litre of water. According to Moberg (1925) 3.1 cc of Diatoms measured 1 mg in dry weight, then 229 cc equals 74 mg. As the volume of water in Mutsu Bay measures 70,000 million cubic meters 74 mg per litre results in 5180 tons of dry matter.

As regards the species of plankton Diatoms Yendo (1905) reported 50 species from the plankton of Misaki, Japan. Okamura (1911) enumerated 57 species from the coastal waters of Japan. Akatsuka (1914) counted 202 species from the plankton of Takashima (Hokkaidô), including, however, many meropelagic species. Gran and Angst (1931) reported 93 pelagic species from Puget Sound. Allen and Cùpp (1935) found 127 species from the plankton of the Java Seas. Kokubo (1929) found 160 species from the neritic plankton collected at the sixteen coastal stations of Japan. In the present investigation 129 species of plankton diatoms have been found.

Of many genera which appear in plankton there are but few genera which have quantitative importance. Kokubo (1931-1940), in his study of plankton Diatoms enumerated the main genera of Diatoms as follows, in quantitative order: (1) *Skeletonema*, (2), *Chaetoceros* (3) *Thalassiothrix*, (4) *Thalassiosira*, (5) *Nitzschia*, (6) *Eucampia*, (7) *Asterionella*, (8) *Rhizosolenia*. But the degree of importance somewhat varies according to the method of measuring. In the above study the measurement was made by counting the number of cells per litre of water, thus resulting in the first abundance of *Skeletonema* which is composed of numerous minute cells. However in the present study in which the volume of Diatoms was measured the first part is taken by *Chaetoceros* which is provided with numerous long setae. In the present study the quantitative importance of each genus according to rough estimation seems to have been as follows. (1) *Chaetoceros* (2) *Coscinodiscus*, (3) *Nitzschia*, (4) *Skeletonema*, (5) *Rhizosolenia*,

(6) *Asterionella*(7) *Biddulphia*, (8) *Thalassiothrix*.

As can be seen in Table I and II the number of genera occurring in the present study included the following 32 genera.

<i>Amphora</i>	<i>Cyclotella</i>	<i>Navicula</i>
<i>Actinopterychus</i>	<i>Dactyliosolen</i>	<i>Nitzschia</i>
<i>Asterionella</i>	<i>Diploneis</i>	<i>Pleurogramma</i>
<i>Asteromphalus</i>	<i>Ditylum</i>	<i>Pleurosigma</i>
<i>Bacteriasterum</i>	<i>Eucampia</i>	<i>Rhizosolenia</i>
<i>Biddulphia</i>	<i>Guinardia</i>	<i>Skeletonema</i>
<i>Campylodiscus</i>	<i>Hemiaulus</i>	<i>Stephanopyxis</i>
<i>Cerataulina</i>	<i>Hemidiscus</i>	<i>Thalassionema</i>
<i>Climacodinium</i>	<i>Lauderia</i>	<i>Thalassiosira</i>
<i>Corethron</i>	<i>Leptocylindrus</i>	<i>Thalassiothrix</i>
<i>Coscinodiscus</i>	<i>Licmophora</i>	

As has previously been stated Diatom studies can be important: firstly for quantitative reasons, i.e., from the standpoint of productivity of the sea; secondly for hydrographic reasons, i.e., as they serve to discriminate whether a water mass is tropical, subtropical, arctic or neritic in its origin; and thirdly for the reason of taxonomic interest. Such relations of the Diatoms have attracted the attention of planktologists, and a good many studies hitherto have been made. But it should be noted that the particulars of these points vary according to the locality. For instance it often results that at a certain locality a certain species becomes the indicator of warm current, while in another locality another species is the indicator of warm current. Likewise in the case of Diatoms vegetation in a definite season the species flourishing then greatly differ according to the locality. Also, as regards the species of Diatoms the endemic species naturally vary with locality.

Therefore such a study should be made in any locality where it is thought to be important to analyse the conditions of movement or mixing of water masses, and especially when it is hard to study such relations by the ordinary method of physical or chemical oceanography. For such purposes of biological oceanography the characteristics of each species of Diatoms must thoroughly be studied every where, like the present case of Mutsu Bay. In what follows descriptions of Diatoms will be given, importance being attached to their ecology. However, it should be borne in mind that the ecological characteristics especially their being an indicator of ocean current, are mainly applicable for Mutsu Bay and for the Japan Sea. As concerns of the Pacific side of Japan they must be studied separately as the present results may not possibly be applicable there.

(1) *Chaetoceros*

Putting aside the taxonomical significance and characteristic of *Chaetoceros* there can be no objection to saying that the genus *Chaetoceros* is the most impor-

tant genus of the pelagic Diatoms in the practical sense. The importance of this genus is not only that it includes numerous species, most of which are pelagic, either neritic or oceanic, but also that some species of this genus have the power of vigorous vegetation, being the primary producer of organic matter in the sea. The number of species of *Chaetoceros* hitherto found in the world is tremendous, though some of them seem to be doubtful. Concerning the species of Japanese *Chaetoceros*, Yendo (1905) enumerated 6 species; Okamura (1907) 26 species; Akatsuka (1914) 36 species; Ikari (1926-1928) 30 species; Kokubo (1931-1940) 30 species.

In his work Gran (1905) illustrated 49 species which were found in north European seas; Gran & Angst (1929) found 25 species in Puget Sound, Washington; Lebour (1930) illustrated 59 species from the plankton of northern seas of Europe; Hustedt (1930) illustrated 66 species as hitherto known exact species; Allen and Cupp (1935) reported 22 species from Java Sea; Cupp (1943) found 44 species along the west Coast of North America. Summing up the above literatures it follows that the *Chaetoceros* of the world are of about 117 species, of them the Japanese species being about 74 species.

In the present investigation 51 species (Table II) of *Chaetoceros* were found, the number of species covering about 40% of the total Diatom species aforementioned (129 species). This percentage alone is evidence of the importance of *Chaetoceros* in the realm of pelagic Diatoms. As to the species of *Chaetoceros* of Mutsu Bay 6 further species (*Ch. lacinosus*, *Ch. seiracanthus*, *Ch. Frickei*, *Ch. pacificus*, *Ch. holsaticum*, *Ch. pelagicus*) which were found in other years must be added, the number of species thus coming to 7 in all.

(a) *Power of the vegetation of Chaetoceros.* It is well known that when the Diatoms show a prominent vegetation the *Chaetoceros* often plays a major part, the association sometimes consisting of *Chaetoceros* exclusively. In Mutsu Bay, too, such has very often been the case, suggesting that the power of vegetation i.e. the production power of *Chaetoceros* is enormously large. According to the author's results (Kokubo, 1932) in Mutsu Bay in 1929 the vernal and autumnal maximum of Diatoms were respectively observed on March 30th and Sept. 1st, both being mainly due to the vegetation of *Chaetoceros*. In the vernal maximum the percentage of *Chaetoceros* to total Diatoms was about 90% (in cell number) and in the autumnal maximum the percentage was about 81%. According to Ueno & Ogawa (1951) who studied the summer plankton (August) of Bungo Channel (Pacific coast) the individual number of *Chaetoceros* per cubic meter of water, in an example was about 3,530,000 the number being about 60% of the total number of Diatoms. But this does not indicate that all species of *Chaetoceros* vegetate equally actively. In their case the flourishing was mainly due to the vegetation of *Ch. pseudocurvisetus*, a tropical species. Other species secondary to this were *Ch. compressus*, *Ch. decipiens*, and *Ch. affinis*.

Thus it is obvious that *Chaetoceros* has great power of producing organic matter in natural seas. But the mass, i.e. density, of organic matter produced by them greatly varies with species. This is because each species of *Chaetoceros* has different cell structure, some species having a very thin cell wall and dilute cell contents, while others have a thick cell wall and concentrated cell contents. Examples of the former are *Ch. distans*, *Ch. laciniosus*, *Ch. brevis*, *Ch. anasiomosans*, *Ch. costatus* and *Ch. rostratus*, and those of the latter being *Ch. coarctatus*, *Ch. atlanticus*, *Ch. borealis*, *Ch. affinis* and *Ch. decipiens*, *Ch. densus*. In considering the productivity of *Chaetoceros* it should be noted that because the vegetation activity is great it does not necessarily follow that each species of *Chaetoceros* propagates equally vigorously. The vegetation power of each species is largely determined by its proper nature. However good the conditions may be some species never propagate profusely, while other species vegetate actively provided only that the environmental conditions are suitable.

In so far as the *Chaetoceros* of Mutsu Bay is concerned the species which have the power of vegetating very profusely, and consequently govern the productivity, seem to be the following 12 species.

<i>Ch. affinis</i> *	<i>Ch. socialis</i> *
<i>Ch. decipiens</i> *	<i>Ch. compressus</i> *
<i>Ch. didymus</i> *	<i>Ch. curvisetus</i>
<i>Ch. debilis</i> *	<i>Ch. constrictus</i>
<i>Ch. subsecundus</i> *	<i>Ch. radicans</i>
<i>Ch. distans</i> *	<i>Ch. setoensis</i>

Of the above 12 species the ones which are denoted with asterisks are the most important not only in Japan but also anywhere in the world. Other than the above species Ueda (1950) reports the immense occurrence of *Ch. coarctatus* and *Ch. denticulatus* in Uranouchi Bay. According to Ueno & Ogawa (1951) *Ch. pseudo-curvisetus* predominated among the Diatoms of Bungo Channel in August 1950.

But such a rank of productiveness is not always common in all localities. For instance, Allen (1945) ranked the species of *Chaetoceros* of Southern California in the following order; *Ch. radicans*, *Ch. compressus*, *Ch. concavicornis*, *Ch. debilis*, *Ch. lorenzianus*, etc. This order is, however, quite unlike that in Mutsu Bay, convincing us that an example in one place is not always indicative of another place.

(b) *Chaetoceros* as an Indicator Species. As respects the use of Diatoms as an indicator of water masses there can be distinguished two integrated types of study.

- I. Patterns of water in a certain area are studied and compared with respect to the quantity or species of Diatoms. The water mass or flow of water can be detected by tracing the water with the same density or same kinds of

Diatoms. This is partly based on the idea that the inshore water is rich in neritic Diatoms, while the offshore water contains a few oceanic Diatoms. Such studies are concerned with the distribution of Diatoms in a wide area. Cleve's classical work and later, many works in which the types of phytoplankton in the North Atlantic were studied are examples of this kind. From then on Sverdrup & Allen (1940?) studied the water masses and currents of South California by counting the number of Diatom cells.

- II. Diatoms occurring in a definite station are studied through all seasons, importance being attached to the taxonomical as well as ecological characteristics, so as to reveal whether it is tropical or subtropical, arctic or subarctic, or if it is a temperate species. If this is thoroughly studied the nature of water masses frequenting the location can be determined by the study of Diatom species. Early appearance of tropical species in quantity in a certain year will represent greater strength of warm current in that year. This is a very exact method as some species of Diatoms particularly prefer their proper temperatures.

In this regard *Chaetoceros* is especially suited for the present purpose, provided that the investigator is trained to identify enough species. The close identification of the species of *Chaetoceros* is indeed a tiresome work, yet it is worth while doing this as it is very important as an indicator. The more experienced the worker in the *Chaetoceros* study the more his capability of using indicator species increases. According to the results of the present investigation the species of *Chaetoceros*, as classified by temperature conditions, can be tabulated as follows.

- (1) Tropical species. *Ch. coarctatus*, *Ch. diversus*, *Ch. messanensis*, *Ch. pseudocurvisetus*.
- (2) Subtropical species. *Ch. anastomosans*, *Ch. costatus*, *Ch. denticulatus*, *Ch. lacinosus*, *Ch. Lauder*, *Ch. paradoxum*, *Ch. rostratus*, *Ch. tetrastichon*.
- (3) South temperate species. *Ch. affinis*, *Ch. brevis*, *Ch. crinitus*, *Ch. curvisetus*, *Ch. distans*, *Ch. didymus*, *Ch. Frickei*, *Ch. lorenzianus*, *Ch. setoensis*, *Ch. siamense*, *Ch. Weissflogii*.
- (4) North temperate species. *Ch. aff. v. Willei*, *Ch. borealis*, *Ch. compressus*, *Ch. constrictus*, *Ch. danicus*, *Ch. debilis*, *Ch. decipiens*, *Ch. deci. v. singularis*, *Ch. densus*, *Ch. holsaticus*, *Ch. mitra*, *Ch. radicans*, *Ch. seiracanthus*, *Ch. socialis*, *Ch. subsecundus*, *Ch. tortissimus*.
- (5) Boreal and arctic species. *Ch. atlanticus*, *Ch. concavicornis*, *Ch. convolutus*, *Ch. conca. f. volans*, *Ch. teres*.

In the above the Diatoms were classified into 5 ecological groups. Of these species the tropical and subtropical species which distinctly indicate the Tsushima Current are the following 7 species; *Ch. diversus*, *Ch. messanensis*, *Ch. anastomosans*, *Ch. coarctatus*, *Ch. pseudocurvisetus*, *Ch. rostratus*, and *Ch. costatus*. All these

species are very scarce in quantity, especially *Ch. diversus* which is the most accurate representative of tropical Diatoms, being of least abundance. In terms of comparative abundance another five species are ; *Ch. costatus*, *Ch. anastomosans*, *Ch. rostratus*, *Ch. messanensis* and *Ch. laevis*. Of the above five species the fore-runner in each year is *Ch. costatus*, usually appearing in mid-September, followed by *Ch. coarctatus*, *Ch. anastomosans* and *Ch. rostratus*. *Ch. messanensis* and *Ch. coarctatus* are well known tropical species ; being however, marked eurytherm species, their northern distribution reaches as great a distance as to the west coast of Hokkaidô or sometimes even the west coast of Saghalien. Contrasted with these two species *Ch. diversus* is by far more tropical in ecological nature, but because of its stenotherm character it perishes before it reaches the west coast of Hokkaidô.

As respects the distribution of the above tropical Diatoms on the Pacific side of Japan available data seems to have been very scarce. Ueda (1945) reported the presence of *Ch. diversus* and *Ch. messanensis* in Uranouchi Bay (Pacific coast of Kôchi Prefecture), the former occurring in November and the latter during the period from November to December. Ueno & Ogawa (1950) studied the plankton Diatoms off Shionomisaki (Wakayama Prefecture) and reported the occurrence of *Ch. messanensis*, recording however no *Ch. diversus*. The same authors (1951) thereafter recorded *Ch. diversus* and *Ch. messanensis* in Kii Channel. Regarding the northernmost distribution of *Ch. diversus* there seems to be no data excepting for the above two studies. As to the distribution of *Ch. messanensis* and *Ch. coarctatus* it is surmised that they probably reach the coast of southern Hokkaidô, because they are eurythermal species.

As stated elsewhere the boreal and arctic species listed in the foregoing table do not appear so regularly in Mutsu Bay as do the tropical species, their abundance being very low in addition. This is due to the fact that the influx of boreal water from the Japan Sea during May is rather erratic, its strength being very weak.

The south and north temperate species which comprise the bulk of the Diatoms of Mutsu Bay are very difficult to distinguish from one another. The distinctions between south temperate and subtropical, between north temperate and boreal are also difficult, as Diatoms of each group have the power of adaptation, being capable of thriving in a certain range of temperature. For instance despite the fact that the *Ch. atlanticus* is a typical arctic and oceanic species it thrives in Uranouchi Bay, a milieu like a salt lake, in Tosa, a warm district in southern Japan. Another instance of this kind is *Ch. messanensis* aforementioned. This species is a typical one, but it is also found, though rarely, on the west coast of Saghalien.

(2) Autecology of important *Chaetoceros*.

The description of *Chaetoceros* given here are mainly concerned with the ecology of each species, the common description of morphology being curtailed except

for special cases. This is because in usual cases of plankton study the knowledge of each species of Diatoms hoped for by practical investigators is autecological descriptions which may be of direct use to them.

Sp. 1. *Chaetoceros affinis* LAUDER.

The present species ranks the first, in its abundance, of *Chaetoceros* which dominates the plankton of Mutsu Bay, its productiveness being second to none of the phytoplankton. The vegetation of this species is important because it supplies food not only for the fishes or clams but also for the animal plankton such as Copepoda and Protozoa; thus it becomes the effective origin of fishery production.

On examining the stomach content of sardine by microscope one will often notice that the terminal spine of this species is left undigested in a great quantity, proving to what extent the sardine subsists on this plant. It is also commonly found that *Noctiluca scintillans* is devouring this *Chaetoceros*; their stomachs are often found to be full of this species.

As regards the seasonal history *Ch. affinis* is generally believed to be a south temperate species. Indeed in Mutsu Bay it usually flourishes in spring or autumn, sometimes during summer, avoiding the coldest season of the year. But on close observation it is found to be present in small numbers all the year round. In case of seasonal change it usually appears after the decline of winter species such as *Ch. debilis* and *Ch. socialis*, or subsequent to the vegetation of *Ch. decipiens*, but never appearing in so warm a conditions as *Ch. distans* prefers. Warm temperate as it is, it is very often observed that it flourishes preceding the vegetation of *Ch. decipiens*, which is usually thought to be boreal or north temperate in nature.

In Mutsu Bay two forms of this species, i.e. forma *singularis* and forma *circinalis*, are found. The former is found mainly during the period from May to July, though very low in abundance. Peculiar to this form is the spine which runs parallel with the apical axis. The present form usually occurs together with the type, but in some cases it appears in plenty when the type is almost absent. Forma *circinalis* which has peculiarly curved spines occurs very rarely. Other than the above forms *Ch. affinis* v. *Willei*, a well known variety of this species, is also commonly found in Mutsu Bay.

Concerning the morphology of this species it is well known that it varies its shape remarkably. Seasonally it is remarkable that the "foramen" of this species is wide during summer and narrow during winter. Though this is a well known fact about *Ch. decipiens*, it is also the case with *Ch. affinis*. When the "foramen" is narrowed extremely its form approximates the shape of v. *Willei*; this reminds the author that Ostenfeld stated that v. *Willei* is the northern form of *Ch. affinis*. Another interesting point respecting morphology is the "spinule" found on the valve of the terminal cell. The present author observed that this 'spinule' is prominent in southern samples and is small or invisible, sometimes completely

absent in northern samples. There seems to be a slight tendency that in a temperate locality the "spinule" is more marked in summer than in winter. Probably for this reason the authors (Allen & Cupp, 1935) who observed southern materials gave figures in which the "spinule" is drawn distinctly, while the authors (Gran 1905, etc) who studied northern materials gave figures without "spinule". At any rate the form of *Ch. affinis* shows remarkable changes seasonally and locally; this may be the reason why different authors gave different figures which often confuse beginners.

Sp. 2. *Chaetoceros anastomosans* GRAN.

Ch. anastomosans is a quite particular species in having a peculiar spine which is very thin and delicate, connected with corresponding setae of the next cell by a bridge-like spine called "cross piece". From this peculiarity the present species can never be confused with other species. However, the cell wall and setae are so thin that its peculiar existence may often be overlooked when it is overwhelmed by other species.

Probably for the above reason the present species has so far attracted but little attention in Japan. Except for Ikari's (1926-1928) report in which it was found at Oshoro (Hokkaidô) and Seto (Wakayama Prefecture) no record seems to have been made. Although Ikari found it at Oshoro Akatsuka (1914) did not record it at Takashima (Hokkaidô), hinting the scarcity or absence of this species in localities further north than Oshoro. The present species is south temperate or subtropical. This is evident from the locality so far recorded by Ikari (1926-1928), Cupp (1943) and Lebour (1930).

In Mutsu Bay the present species occurs from October till late November, and suggests the influx of Tsushima Current, it being the indicator of warm current. As to its origin it is surmised that the present species was probably produced from the South China Sea or thereabout, as it is not recorded in the Java Sea by Allen & Cupp (1935). By nature the present species seems to be incapable of showing vigorous vegetation; its abundance in Mutsu Bay is very low.

Sp. 3. *Chaetoceros atlanticus* CLEVE.

Ch. atlanticus is well known as a typical arctic and boreal species. Due to its pronounced feature it can never be confused with other species. The morphological peculiarity consists in that its shell is more or less large and robust, it has thick setae; and each valve of the cell is provided with a conspicuous spine (spinule), thus showing an impressive feature.

The present author (Kokubo, 1931-1940) has found this species in the plankton catches of northern Japan, especially in winter, e.g. in moderate abundance at Hanasaki and Takashima in Hokkaidô. Aikawa (1936) stated that this species is common as a plankton of Oyashio Current. Though this species is said to be arctic one its eurythermal character allows its distribution to extend as far

south as Kôchi Prefecture. Oceanic as it is, it is found in an enclosed region of Uranouchi Bay, a stagnant inlet like a lake in the Pacific coast of Kôchi Prefecture. In Mutsu Bay it is an indicator of cold current and has been found during May to June in low abundance, its origin probably being the northern waters of the Japan Sea. As respects the quantity of this species it is likely that because of its oceanic nature it does not show active vegetation, at least in neritic regions.

Sp. 4. *Chaetoceros coarctatus* LAUDER.

Ch. coarctatus is one of the most representative tropical Diatoms, having a characteristic form which enables even beginners to distinguish it from other species. The first characteristic which gives this species a salient feature is its spines. The terminal spines, especially the posterior ones, of this species are extraordinarily thick and robust, in some cases as thick as the frustule itself. The second characteristic is that it usually has attached to it a species of *Vorticella*, sometimes in such large numbers that it looks as if it was wholly covered with these organisms. From these characteristics a colony of *Ch. coarctatus* gives the observer an impression of great massiveness and heavy feelings.

Ch. coarctatus is a well known tropical and subtropical species, being very common in southern seas. According to Wood (1951) in Australian waters this species is an indicator of tropical current, occurring from New Guinea to Montague Island and farther south. As to the seasonal history of this species in Mutsu Bay it has been found that it usually appears very much earlier than other tropical species. The earliest record of the occurrence of this species has been July 21st 1950 and the latest record has been December 12th 1948, the interval being the warm season. Akatsuka (1914) reported that this species appears during summer at Takashima (Hokkaidô) where other tropical species are found only rarely. These records suggest the difference of this species from other tropical species which usually appear from October on. This is probably because this species is no doubt a tropical species, but with very wide adaptability to varying temperatures. And hence in its native seas it begins the northward travel in advance of other tropical species, thus being enabled to reach far north relatively early.

Sp. 5. *Chaetoceros concavicornis* MANGIN.

Among many species of *Chaetoceros* there are several species in which all setae bend toward the lower end of the chain. The most prominent one of this kind is *Ch. coarctatus* above mentioned. The second to this is the present species which, however, greatly differs from *Ch. coarctatus* in other respects, and generally seems to occur nowhere in great abundance. Though its abundance is limited its occurrence deserves attention because it is oceanic and is an indicator of cold waters. According to Akatsuka (1914) *Ch. concavicornis* occurs during the period from January to July, avoiding the warm period. In Mutsu Bay a quite similar tendency was observed in 1950, and moreover another tendency that this species

enters into Mutsu Bay during May from without was observed (Kokubo, 1950).

The present species has a forma called *Ch. concavicornis* f. *volans*. This forma is well distinguished from the type by its being a solitary cell. Of this forma it is striking that its seasonal occurrence is almost reversed as compared with the type, which thrives in cold water, viz., this forma occurs during the warm season of the year. Such a relation is markedly shown by Akatsuka (1914), in his study of the Diatoms of Takashima. Cupp (1943) also suggested that this forma is more southern than the type. But in Mutsu Bay such has not been necessarily the case; the forma often occurs in company with the type.

Sp. 6. *Chaetoceros convoltus* CASTRACANE.

Ch. convoltus is a species very similar in its appearance to the preceding one. It has setae bent downwards, being however, distinguishable in the following points: (1) the setae of *Ch. convoltus* are relatively thin, armed with thin slender spines, while those of *Ch. concavicornis* are more or less thick and armed with thick, conspicuous spines; (2) the girdle zone in "Ruhezellen" is distinct in *Ch. convoltus*, having a notch at the suture, while it is rudimentary in *Ch. concavicornis*; (3) in *Ch. convoltus* the girdle zone is about one third of cell length, while it is narrower in *Ch. concavicornis*; (4) the chain is more or less twisted in *Ch. convoltus*, while in *Ch. concavicornis* it is not twisted.

Ch. convoltus is alike also in its ecology to *Ch. concavicornis*, being boreal and arctic. Probably because of being oceanic in nature it occurs in Mutsu Bay in a lowest abundance every year. Its appearance in May is probably caused by the influx of oceanic water from Tsugaru Strait. Akatsuka (1914) reported only a few occurrences of this species in February and March at Takashima, this time interval being reasonable as seen from its proper nature. Astonishing, as respects the present species, is Cupp's (1943) results in which as high an abundance as 1,500,000 per litre was recorded to occur frequently off southern California.

Sp. 7. *Chaetoceros constrictus* GRAN.

Ch. constrictus is one of the important species in Mutsu Bay, sometimes showing high abundance. This species is generally known to be of neritic and north temperate nature. Akatsuka (1914) reported that at Takashima (Hokkaidô) this species occurs through all seasons, being, however, most abundant during the period from December to March, i.e. the coldest season of the year. In Mutsu Bay, too, this is the plankton of the winter season, usually occurring from January to May; in 1949, however, it was found in November and December in a great abundance.

In identifying the present species care should be taken so as not to confuse it with *Ch. Van Heurckii*. The latter species, which appears during autumn in Mutsu Bay, is closely allied to the present species and can be distinguished by the structure of the resting spore, and by slightly thicker terminal setae. The resting

spore of the present species has no pallisade spine on the secondary valve; that of *Ch. Van Heruckii* has.

Sp. 8. *Chaetoceros compressus* LAUDER.

Ch. compressus is a distinct and important species distributed from south temperate to boreal seas, and often found in arctic seas in abundance. In Mutsu Bay it vegetates from February to April, and also from August to September, but in small number it is found all the year round. Cupp (1943) stated that *Ch. compressus* is a very important species along the California coasts, and is found abundantly off southern California from March to June, and in some years again in November and December.

Ch. compressus is a small sized species as compared with others and has a unique characteristic in having particularly thick, short and waved setae here and there in the colony. These spines give the colony a peculiar appearance, and makes it possible to distinguish them very easily from other species, except for rare cases in which a colony develops none of the above setae.

Sp. 9. *Chaetoceros costatus* PAVILLARD.

Ch. costatus is a small *Chaetoceros* which has the characteristic of having many intercalary bands on the girdle of the frustule by which it is distinguished from common species. In Japan the present species has so far been very little known, the only record probably being Ikari's (1926-1928) study which reports it at Seto (Wakayama Prefecture). According to Cupp (1943) this is a warm water species and is found in great abundance in the Gulf of California. In Mutsu Bay it occurs only in low abundance from September till December and is an indicator of the Tsushima Current, probably being of south temperate or sub-tropical nature.

Sp. 10. *Chaetoceros debilis* CLEVE.

Ch. debilis is a species easily distinguishable from other species by its characteristic feature: chains strongly curved and twisted, with curved setae and without special terminal cells. The present species is one of the most important species in its abundance, being second to none in productive power of the organic matter.

This is a well known cold water species, and is regarded as an arctic species by some authors (Lebour, 1930) (Gran, 1905), and as a north temperate species by another author (Cupp, 1943). According to Akatsuka (1914) *Ch. debilis*, at Takashima, occurs during the period from October to April, the highest abundance being observed from November to January. Ueda (1950) studied *Chaetoceros* of Uranouchi Bay, where the temperature conditions are very much warmer than in Mutsu Bay, and stressed that *Ch. debilis*, which abounds in northern localities, shows very low abundance there.

In Mutsu Bay the first occurrence of this species is usually observed in late

November, and it shows maximum occurrence during the coldest season, i.e. from late December to late March, being especially abundant in February. A sparse occurrence, however, can be observed in any season of the year, even during summer.

In Mutsu Bay the appearance of *Ch. debilis* in late November signifies the change of plankton from autumn into winter form. The cod fishing of Mutsu Bay, which occurs from early December, seems to produce rich catches when *Ch. debilis* and *Ch. socialis* show high abundance, provided the disappearance of warm species is complete. Therefore the observation of this species from mid-November on is indispensable work for estimating the catch of cod.

Sp. 11 *Chaetoceros decipiens* CLEVE.

Of the *Chaetoceros* above mentioned each is important either as an indicator species or because of its numerical abundance, viz., production power. But when considered from the viewpoint of organic production it can be said that *Ch. affinis* and *Ch. decipiens* are the most important species, both being almost equally abundant in temperate seas. Generally speaking, however, it has been related that *Ch. affinis* is warm temperate and *Ch. decipiens* is of boreal or arctic habit. Indeed it is virtually so, the former being found in the tropics in plenty while the latter is found not at all in the tropics. However, in temperate localities the production power of *Ch. decipiens* is not less than that of *Ch. affinis*, as the former is extremely eurythermal, and consequently is enabled to vegetate there very actively.

From the proper habit of these two species it is naturally thought that in vernal vegetation *Ch. decipiens* precedes *Ch. affinis*, while in autumnal vegetation vice versa. This tendency is usually observed, but often this was not the case, probably because of other governing factors such as nutriment condition or light condition etc.

According to Akatsuka (1914) *Ch. decipiens* at Takashima occurs through the year, but high abundance is found in February, March, July, August and November, maximum abundance being in July. Ueda's (1950) study, previously quoted often, was carried out in a very warm locality, the result showing that *Ch. decipiens* is one of the abounding species, and in his case it was notable that high abundance was restricted to the coldest season from December to March, in the rest of the year little abundance being shown. This seasonal history can reasonably be understood from the proper nature of this species above mentioned. In Mutsu Bay the scant occurrence of this species is seen through all seasons, but the time of regular increase differs according to year. During the successive four years of 1947-1950 the occurrence of *Ch. decipiens* was relatively scanty except for the year 1950 in which high abundance was observed during the period from October to December, and the next abundance was seen in April, August and September. In the author's (1932) former work *Ch. decipiens* was found in

abundance during 1929-1930. In 1929 a high abundance was seen in May, followed by the highest abundance in September. In 1930, too, a high abundance was observed in May, the highest abundance being found in August.

Before ending this description a few lines will be given for relating *Ch. decipiens f. singularis*, which occurs, though rarely from April to December. The cell of this forma is solitary as in *Ch. affinis f. singularis*. But in the present forma the direction of setae utterly differs from that of the former, because its setae run paralld with the perival axis, in opposition to those of *Ch. affinis f. singularis* in which the setae run paralld with the apical axis.

Sp. 12. *Chaetoceros didymus* EHRENBERG.

Ch. didymus is generally known as a warm temperate species, occurring in southern localities in great abundance. Among the *Chaetoceros* of Mutsu Bay this is also one of the main species, showing active vegetation according to year. In some years this species becomes an important component of vernal or autumnal flourishing, but its abundance is mostly second to *Ch. affinis*, *Ch. decipiens*, *Ch. debilis* and *Ch. distans*. Akatsuka's (1914) results show that at Takashima *Ch. didymus* is almost absent for the first half of the year, and that it begins to occur from late July, attaining a maximum during September and October, then decreasing rapidly by December. According to Ueda (1945), whose study was made in a southern locality, *Ch. didymus* was a very important species, taking third rank among many species, and occurring throughout the year except for August and September. However, in the author's former study (Kokubo, 1932) this species was found to occur from August to December, showing maximum vegetation in September. In the present study the occurrence of this species was relatively scarce, but comparative abundance was also high in September.

Sp. 13. *Chaetoceros distans* CLEVE.

Ch. distans is one of the most important species not only in Mutsu Bay but also any where in northern Japan as far as neritic water is concerned, it being a prominent north temperate species. The present species often vegetates so vigorously as to rival such important species as *Ch. affinis* or *Ch. decipiens* which are the main producers of organic matter in the sea.

In Japan the present species was reported for the first time by Okamura (1907) from Goza (Mie Prefecture), giving a figure with resting spore. Gran & Yendo (1914) recorded this species from Misaki (Kanagawa Prefecture) and Misumi (Kumamoto Prefecture) together with *Ch. laciniosus*. Akatsuka (1914) described a *Chaetoceros* sp. from Takashima (Hokkaidô) referring it to Okamura's (1907) *Ch. distans*. According to him the present species occurs in the greatest abundance during August and September, a warm season, and in least abundance during the period from January to March, occurring, however, all the year around sparsely.

The author's results in Mutsu Bay are very similar to Akatsuka's results as to seasonal occurrence. In Mutsu Bay the highest abundance of this species was likewise found during the period from August to October, the warmest season, throughout the four years of 1947-1950, sparse occurrence having been observed through all seasons. In October 1944 the author found the present species vegetated vigorously in Yoshanaikai Bay (Kyoto District).

Regarding *Ch. distans*, the form variation in respect to its cell breadth is of interest. This species changes its cell breadth to a great extent; consequently accompanying a form change of the resting spore.

In Mutsu Bay during summer the breadth of cell of this species varies between 6.6-28.2 μ . If one draws the frequency curve in relation to cell breadth there will be found two distinct modes, the narrow one at 10.8 μ and wider one at 27 μ . These two modes probably represent the different generations of the cells, the narrower and wider cells respectively in the states before and after the development of auxospore.

Sp. 14. *Chaetoceros diversus* CLEVE.

Ch. diversus is a pure tropical species, being found so far by Gran & Yendo (1914) at Enoshima (Kanagawa Prefecture) and Akashi (Hyogo Prefecture), and also in the Fōrmosa Channel by Schröder. The chain is usually composed of 2-4 cells, and is characterized by its thick, diverse and long setae.

There is another tropical species called *Ch. laevis* which is also found in Japan (Okamura, 1907), and has an appearance quite similar to the present species, but has not so far been found in Mutsu Bay. This species is distinguishable from the present species by its prominent setae which are at first perpendicular to the chain axis, then bent at right angles, running parallel to the chain axis.

In Mutsu Bay *Ch. diversus* is a most decisive indicator of the Tsushima Current, usually occurring during October and November. The fact that this species had not been found by Akatsuka (1914) seems to suggest its stenotherm character as compared with *Ch. messanensis* because it is reasonably thought that due to this reason the present species perishes before it reaches Takashima of Hokkaidō.

Sp. 15. *Chaetoceros messanensis* CASTRACANE.

Among the many species of *Chaetoceros* there are several species which can in no way be confused with other species due to their peculiar characteristics. Perhaps the present species would represent these peculiar species, having extraordinary big bifurcated setae which are visible under low magnification like the spicules of sponge, despite the fact that other parts are quite invisible.

Ch. messanensis is a tropical and subtropical species, but its distribution towards the north seems to be very wide, attaining as high a latitude as 49° N in the Atlantic. Such a wide distribution must be due to the wide adaptability of this species to temperature change. The present author (Kokubo, 1931-1940)

studied the distribution of this species in the Japan Sea, and found it at Rakuma (West coast of Saghalien) in an abundance of 240 cells per litre on September 2nd 1932. A fairly high abundance was found at Hamada (Shimane Prefecture) where it appeared in maximum in autumn, on September 17th 1931, the cell number being 2,228 per litre.

Sp. 16. *Chaetoceros peruvianus* BRIGHTWELL.

Ch. peruvianus is a warm water species and is said to be a south temperate species, occurring in Mutsu Bay mainly during the warm season, but sparsely it is found in different season of the year. The vegetation of this species is very limited so that it is not important quantitatively.

It was with the following anxieties that the present author identified this species (1) the hollow channel of the girdle-band margin is indistinct, though according to Cupp (1943) this must be distinct; (2) unlike typical specimens the striations on the setae are somewhat indistinct; (3) the setae are relatively slender. From these characteristics it seems that the specimens are more or less far from being the typical species, rather approximating *Ch. pendulus*.

Sp. 17. *Chaetoceros pendulus* KARSTEN.

Ch. pendulus is a species closely allied to the foregoing species, this resemblance often being very confusing. The seasonal history of this species seems to be almost identical with that of *Ch. peruvianus*, and it sometimes occurs together with the latter species. For instance in Mutsu Bay on July 23rd 1949 both species occurred concurrently, making convenient comparison possible.

On examining the specimens it was found that the deep depression on the upper valve, which is the characteristic of *Ch. pendulus* was absent, and that the width of cells was not so small as *Ch. pendulus*, but was as large as *Ch. pendulus*, commonly attaining 33μ . These points suggested to the author the possibility of morphological interchange between *Ch. peruvianus* and *Ch. pendulus* under certain circumstances.

Sp. 18. *Chaetoceros pseudocurvisetus* MANGIN.

Ch. pseudocurvisetus is well known as a tropical and subtropical species, being fairly common in southern waters. But it is rare in northern Japan, distribution being limited only to the locality where warm current prevails. Gran & Yendo (1914) reported the present species from Misumi (Kumamoto Prefecture), stressing its peculiarities which are shown in the connecting warts of the cell. These authors found it also from Penang (Malay Peninsula, 5° N.). Later Ikari (1926-1928) recorded it from Seto (Wakayama Prefecture). Recently Ueno & Ogawa (1950) found this species in a great abundance in the plankton of Bungo Channel (between Kyushû and Shikoku) in August 1950, and also from Kii Channel though scantily. In Mutsu Bay the present species is a decisive indicator of warm current, and is scantily found only during October to November when the

Tsushima Current is at its hight.

Sp. 19. *Chaetoceros radicans* SCHÜTT.

Ch. radicans is also one of the peculiar species for it shows a characteristic feature in its setae, which run parallel with the transapical axis. Because of this the colony always shows a narrow girdle view under the microscope. Moreover the cells, probably also the setae, secrete mucilage on its surface. On account of this mucilage the colony is always densely covered with dust-particles and detritus. As this gives the plant a peculiar feature the experienced investigator determines the present species at a glance.

The present species is a north temperate species with a wide distribution except in tropical or subtropical waters. Vegetation in northern waters is remarkable, often showing a great abundance. According to Cupp (1943), in the Gulf of California, the number of cells reached 4,500,000 per litre in March. In Mutsu Bay this species occurs mainly in the warm season in moderate abundance; though occasionally it occurs also in winter. In 1949 relatively high abundance was observed from July to October.

Sp. 20. *Chaetoceros setoensis* IKARI.

The present species was first reported by the late Ikari (1926-1928) in 1926 as a new species from the specimens collected at Seto (Wakayama Prefecture), Itosaki and Aioi (Setonaikai). After then there seems to have been no record till the present investigation. In Mutsu Bay in 1948, in which an extraordinary high temperature of 29.0°C was recorded in August, *Ch. setoensis* showed a surprising vegetation from November to December. Since then, however, no remarkable vegetation has been observed, even sparse occurrence being rather rare. The sudden appearance of this species in Mutsu Bay is remarkable, and calls for further observation.

Sp. 21. *Chaetoceros socialis* LAUDER.

Ch. socialis is a peculiar species having the characteristic that the numerous circular colonies which are composed of minute cells are buried in a spherical mass of gelatinous substance. This spherical mass is sometimes so large as to be visible to the naked eye as a small granule, and often completely chokes up the mesh of the net when it occurs in a great abundance. The vegetation of this species in northern waters is often tremendous though on the average its abundance comes second to other important species.

The present species is of boreal character, probably by far more northern in nature than what so far been considered, and is found in Japan mainly in northern waters, though its southern distribution extends to Katōjima (Saga Prefecture) or possibly a little southwards. Ueda's (1945) results showed the absence of this species in Uranouchi Bay through all seasons, probably because of the locality being so far south. According to the author's (1931-1940) former results

it was most abundant in Rakuma (Saghalien), next in Hanasaki (Hokkaidô) and thirdly in Mutsu Bay. Strangely Akatsuka's (1914) results show the scarcity of this species in Takashima in spite of its being a northern locality. As stated in preceding pages the present species is an indicator of the winter season in Mutsu Bay, heralding the cod fishery.

Sp. 22. *Chaetoceros subsecundus* (GRUNOW) HUSTEDT.

Ch. subsecundus is commonly understood to be an arctic and boreal species. Its distribution, however, extends fairly far south, e.g. it is found in Uranouchi Bay of Kôchi Prefecture (Ueda, 1945) in moderate abundance. The boreal character of this species is probably not so marked as that of *Ch. socialis*. The abundance of this species in various localities seems to be moderate, it being in most cases second or third to other important species such as *Ch. affinis*, *Ch. decipiens* etc.

According to Akatsuka (1914) the present species occurs during the period from January to August, avoiding the warm season of the year. In concordance with this Ueda's results above mentioned also show its occurrence to be from December to April, the maximum being found in February. In five year's records in Mutsu Bay it occurred from late November to April. Thus the above three records well accord and lead to the conclusion that it avoids the warm season.

(2) *Asterionella* HASSALL.

Asterionella is one of the important genera of pelagic Diatoms, including four well-known marine species: *A. japonica*, *A. kariana*, *A. bleakeleyi* and *A. notata*. The first one is the most common.

Sp. 1. *Asterionella japonica* CLEVE.

Asterionella japonica sometimes occur in extraordinary abundance in marine plankton. In Mutsu Bay, however, this species ordinary shows moderate abundance. At no time of the year does it exceed the other species in quantity. The author's early study (Kokubo, 1932a) showed that in 1930 it ranked third in abundance during October to December, but in 1929 ranked second in abundance during January to February.

In the present study this species showed a moderate abundance during the period from January to March (during the coldest season of the year.) It was found in low abundance during autumn, and more sparsely in May and July. From the present and the former study it can be roughly concluded that the present species occurs principally from autumn to winter. In Mutsu Bay it is obvious that the vegetable productivity of this species is insignificant as compared with *Chaetoceros*.

According to Bigelow (1926) it was found in the Gulf of Marine (1912) in great abundance during July and August. Allen (1928) reported that at La Jolla and Oceanside in California it occurs principally in the first half of the year. In Japan

the species was reported by Yendo (1905) from Misaki, by Okamura (1919) from Shirahama, by Akatsuka (1914) from Takashima in April.

(3) *Bacteriastrum* SHADBOLT.

Bacteriastrum is a pelagic Diatoms characterized by its chain-like colonial structure and also by its great abundance. In Mutsu Bay this genus is of southern nature, occurring principally during autumn. According to Ikari (1927) there are 10 species in the neighbouring waters of Japan, of which more than 6 species are commonly found in Mutsu Bay: *B. comosum*, *B. delicatulum*, *B. hyalinum*, *B. minus*, *B. varians* and *Bacteriastrum* sp.

Sp. 1. *Bacteriastrum varians* LAUD.

In Mutsu Bay *B. varians* is the commonest of this genus. In the earlier study by the author (Kokubo, 1932a) it was found during the period from March to September in 1929 and from May to December in 1930. In the present study it showed a moderate abundance during autumn, especially in October, and was not found at all during the period from March to August.

In Mutsu Bay the highest abundance of this species was 7,492 and 12,386 cells per litre, in 1929 and 1930 respectively. The present study found this species to be much less abundant than it was during the two earlier years. The abundance of this species in Mutsu Bay is second or third in rank; it never ranks first. The contribution of this species to the organic production in Mutsu Bay is surmised to be relatively little at the present time.

The geographical distribution of the present species around Japan is wide, ranging from Saghalien to Formosa, being found from Goza (Mie Prefecture) by Okamura (1919), from Oshoro and Hakodate (Hokkaidô) by Ikari (1927) and from Takashima by Akatsuka (1914).

Sp. 2. *Bacteriastrum hyalinum* LAUD.

Bacteriastrum hyalinum is a peculiar species characterized by the plane of the bifurcation of setae, which is parallel to the chain axis. This is a marked difference from the ordinary species in which the bifurcation is in valval plane.

In Mutsu Bay in 1950 the present species occurred very often. It ranked second, after the above species, in abundance. But this is not usually the case; its abundance has hitherto been lower than that of *B. delicatulum*. In the present study the season of occurrence was found to be similar to that of *B. varians*. Like it, it was not found at all between January and June.

The present species is said to be very common in the North Atlantic, but in Japan it has so far been reported only by Ikari (1927) and only from a southern locality. It has possibly been confused with other species by many authors.

Sp. 3. *Bacteriastrum delicatulum* CLEVE.

Bacteriastrium delicatulum is one of the commonest species of this genus, and is characterized by its cells being more or less elongated, of relatively small diameter which ranges around 10μ . As to the seasonal occurrence of this species Akatsuka (1914) reported it to be from May to August; he considered it to be a boreal species. In the present study it occurred mostly during the warm season of the year. Its abundance was lowest in 1947 and 1915, but in 1946 and 1949 it was found in moderate abundance.

The geographical distribution of this species is very wide, ranging from the tropics to the arctic. In Europe it is commonly found in the North Atlantic, the North Sea, etc, during all seasons. In the Mediterranean it is found in its greatest abundance during spring. According to Allen & Cupp (1935) it is common in the Java Sea. In Japan it is commonly found in different seasons of the year.

Sp. 4. *Bacteriastrium comosum* PAVILLARD var. *hispidum* (CASTR.)

Bacteriastrium comosum v. *hispidum* is strongly characterized by its terminal setae, of which the posterior ones are especially developed, first diverging radially, then bent backwards with thick undulating stem. The anterior setae are thinner and shorter than the posterior ones, and are also bent backwards. A glance at the posterior setae enables one to distinguish this species from others.

In Mutsu Bay this species occurs during autumn, as an immigrant from south. It is one of the distinct indicators of the warm current. Among the genus no species gives a more reliable indication of the presence of the warm current than does this species. In 1946 it was found from September to November; in 1947 during December; in 1948 during September and October; in 1950 it occurred during October and November. In short the present species is a southern species, appearing in Mutsu Bay only during the warm season. It is never found in large number.

Sp. 5. *Bacteriastrium minus* KARSTEN.

The characteristics which distinguish this species are: firstly, that the perval length of cell is small, and consequently the cell looks like a disk; secondly, that the intermediate setae are relatively short and terminal setae not developed, and that its length, likewise, is short. Finally, it is also a characteristic that the colony is usually very short, being composed of several cells. Probably because of these unusual characteristics Akatsuka (1914) reported the present species as "Gen. et Sp. nov.": he was not aware that it was *Bacteriastrium*.

In Mutsu Bay this species occurs seasonally only during September and October. During five years, 1946 to 1950, it was not found in 1947 and 1949. According to Akatsuka (1914) the present species was found at Takashima (Hokkaidô) during summer. Ikari (1927) reported the occurrence of this species from both the Pacific and Japan Sea coast of Japan. The author believes that this is a south temperate species, but its distribution extends as far north as the

north eastern side of Hokkaidô.

(4) *Cerataulina* H. PÉRAG.

Cerataulina is one of the commonest genera of plankton Diatoms. In Mutsu Bay its abundance is not always high, but it should not be considered unimportant, for it plays an important part in other areas.

Sp. 1. *Cerataulina Bergonii* PÉRAGALLO.

Cerataulina Bergonii is a pelagic species with very thin cell walls and delicate cell contents. The vegetation of this species is very vigorous and shows, in some cases, high productivity. Though the present species shows but little abundance in Mutsu Bay, the author once found this species to be vegetating in great abundance during October (1944) in Yoshanaikai Bay (the Japan Sea side of the Kyoto District). Five years of observation, 1946-1950, showed that the seasonal occurrence of this species in Mutsu Bay normally ranges between June and September. Though this species is said to be south temperate the fact that it shows no high abundance during October and November suggests that it is neritic and an endemic species which can seed in northern seas and which vegetates provided the temperature increases normally. If the present species is an immigrant from the south it must occur during autumn, when the flow of the Tsushima Current into Mutsu Bay is at its greatest. According to Akatsuka (1914) seasonal occurrence of this species at Takashima is in August.

(5) *Coscinodiscus* EHRENBERG.

The importance of *Coscinodiscus* as plankton ranks second to *Chaetoceros*. The species of this genus are numerous, and some of them occur in great abundance. They are an important factor in the organic production of the sea. The following ten are commonly found in Mutsu Bay: *C. Angstii**, *C. asteromphalus**, *C. concinnus**, *C. excentricus*, *C. Granii**, *C. lineatus*, *C. marginatus*, *C. radiatus**, *C. subbliens*, *C. Wailesii**. Of these the ones marked with asterisks are most important.

Sp. 1. *Coscinodiscus Wailesii* GRAN & ANGST.

The species *C. Wailesii* can be identified unmistakably because of two characteristics: (1) it is a giant form, the cells ranging from 220 to 400 μ in diameter, (2) its shape is angular-cornered square in side view. According to Gran & Angst (1930) the nearest relative of this species is *C. gigas*, from which these authors separated this species. *C. Janischii*, (differing from the present species in the structure of its central area,) reported by Akatsuka (1914) from Takashima, may possibly be the same as this species.

In Mutsu Bay this species occurs mainly during winter, from January to April. It is found in small numbers all the year round, but it has a tendency to decrease during July and August, indicating that it is a boreal species. In

my long experience in plankton collection the present species occurred in a great abundance in winter in some years, showing a strong power of vegetation. But, during five years, 1946-1950, it showed no remarkable vegetation except during 1949 when it occurred in abundance during March. Akatsuka (1914) also reported the occurrence of *C. janischii* during January. Gran & Angst (1930), however, stated that in Departure Bay, British Columbia, the present species was found during all seasons - most abundantly in summer.

Sp. 2. *Coscinodiscus Granii* GOUGH.

Coscinodiscus has a peculiar form in its girdle view, one side being very much higher than the other. Due to this characteristic it is unmistakable. In addition to this characteristic it is fairly large, the diameter ranging from 100 to 260 μ , and hence it is quite distinct among the neritic plankton Diatoms. In some cases the vegetation of this species is very vigorous, hinting its significance in organic production.

In Mutsu Bay this species shows the highest abundance during late autumn (October-December). From then on it decreases gradually till May. It is rarely found again until the end of August. This is the regular tendency found during five years of observation, 1946-1950. Such a tendency well accords with the seasonal occurrence of tropical plankton in Mutsu Bay, indicating that this species is a southern one, brought in, together with other tropical Diatoms, by the Tsushima Current. Akatsuka (1914) reported the highest abundance of this species, at Takashima (Hokkaidô), to be late autumn (December-January). This does not conflict with the cycle of occurrence in Mutsu Bay, and seems to show that this species is not true winter form. Generally this species has been considered to be north temperate or boreal, but it may possibly have a more southerly nature than so far considered.

Sp. 3 - 10. *Coscinodiscus*: eight other species.

Coscinodiscus Angatii GRAN is one of the common species of this genus in Mutsu Bay, and is characterized by having a variable number of large spines on the valve surface just inside the row of marginal spinules. This character enables one to distinguish it. It never occurs in large number. Seasonally it occurs during early winter (December to February).

Coscinodiscus asteromphalus EHR. is a little more common in occurrence than the above species. Seasonally it occurs mainly during autumn, like *Coscinodiscus Granii*. In Mutsu Bay the productivity of this species is by no means prominent.

Coscinodiscus concinnus W. SMITH is also a common species, with convex valves, and very thin cell wall. It seems to have a rosette in its central area usually. In the Mutsu Bay specimens the central area was transparent, without rosette. Such specimens were also described by Cupp (1943) from California. The seasonal occurrence is very similar to that of the above species. In January,

1947, it showed a little higher abundance than during other years.

Coscinodiscus excentricus EHR. is found commonly in Mutsu Bay ; though its number is limited. The observations of 1946-1950 indicated that, like *Coscinodiscus Granii*, this species increases from late September, showing highest abundance during the period from spring to summer.

Coscinodiscus lineatus EHR. is also commonly found in Mutsu Bay, but its abundance is more meagre than that of the above species. Due to its scant occurrence seasonal relationships are difficult to determine, but its cycle may be supposed to be similar to that of the above species.

Coscinodiscus marginatus EHR. is a small species but it is unmistakable because of its large and robust areolae on the valve surface. It is rather rare in Mutsu Bay. According to Akatsuka (1914) this species was found during from November to March. In all localities its occurrence is more or less sporadic ; this may be due to its benthic nature, not being of true pelagic habit.

Coscinodiscus radiatus EHR. Of the many species of *Coscinodiscus*, the present species has a peculiar characteristic : its occurrence is commonest of all *Coscinodiscus*, being found all the year round in all localities irrespective of salinities and temperatures, yet its power of vegetation is limited, scarcely showing vigorous flourishing in Mutsu Bay. In the five years of the present study it showed a moderate vegetation only once in September, 1946. Akatsuka (1941) at Takashima (Hokkaidô) reported that it appeared from October to April.

Coscinodiscus centralis EHR. (syn. *Coscinodiscus subbliens* Jörg.) is also commonly found in Mutsu Bay, though not in large number. Hustedt (1930) stated an immense occurrence of this species in northern seas, but in the observations reported herein it showed no remarkable vegetation. Seasonal occurrence seems to show relatively high abundance during winter.

(6) *Climacodium* GRUNOW.

Two important tropical species (*C. biconcavum* and *C. Frauenfeldianum*) are included in this genus ; both of them are found in Mutsu Bay, being distinct indicators of the Tsushima Current.

Sp. 1. *Climacodium biconcavum* CLEVE.

Of the two species of this genus *Climacodium biconcavum* differ from other in the manner of the jointing of the cells. In this species the jointing point is more or less like that of *Hemiaulus* ; in *C. Frauenfeldianum* it resembles that of *Eucampia*. These facts cause one to recall the name *Eucampia hemiaulus*, once given to this species by Ostenfeld.

In Mutsu Bay *Climacodium biconcavum* is found during autumn every year in very small number, and indicates the inflow of Tsushima Current. Its cycle of occurrence, however, differ from that of other tropical species, having these characteristics : it appears a little earlier than do the others, (usually from early

or mid-August); its duration of occurrence seems to be more or less shorter than that of other tropical species, never occurring after December. During 1946-1950 it was completely absent only in 1947, and it showed a slightly higher abundance during the period of August-December, 1949. Akatsuka (1914) also reported the seasonal occurrence of this species from Takashima (Hokkaidô) to be from August to December.

Sp. 2. *Climacodium Frauenfeldianum* GRUNOW.

Climacodium Frauenfeldianum is more tropical than the above species. In Mutsu Bay it is rarer than the above two species, being found in very small number. Due to its scarcity the seasonal occurrence is not yet known for certain. In 1950, however, it occurred during the period from September to December, suggesting a delay of this species as compared with the above species.

(7) *Dactyliosolen* CASTRACANE.

The genus *Dactyliosolen* ordinarily contain two species, i.e., *D. mediterraneus* PÉRAGALLO and *D. antarcticus* CASTR. Both are found in Mutsu Bay. The former is fairly common.

Sp. 1. *Dactyliosolen mediterraneus* PÉRAGALLO.

Dactyliosolen mediterraneus PÉRAG. is one of the commonest species, described as *D. tenuis* (CLEVE) by some authors. Numerically the present species is much less frequent than other important species, but it far exceeds such genera as *Eucampia*, *Hemidiscus*, and *Climacodium* in number. With respect to the seasonal occurrence in Mutsu Bay, it was found that it occurs during from March to November, but high abundance was found during the period from June to November. In the present study it was never found between December and February. In short, in Mutsu Bay, the present species is a plankton of warm season.

(8) *Eucampia* EHRENGERG.

Sp. 1. *Eucampia zoodiacus* EHRENBURG.

Eucampia zoodiacus EHR. is a well-known, widely distributed neritic Diatom, occurring in some cases in great abundance. In Mutsu Bay its abundance is never high. In the present study of 1946-1950 it was found that this species occurs almost all the year round, but that it has a slight tendency not to vegetate during July and August. In 1949 it showed a moderate abundance during February. Differing from present species *E. cornuta* (CLEVE) is southern species probably being subtropical. Its occurrence in Mutsu Bay is not fully ascertained but it can probably be found there during autumn.

(9) *Guinardia* H. PÉRAGALLO.

Sp. 1. *Guinardia flaccida* CASTR.

Numerically, and also in productiveness, the present species is not worth special attention, but according to the result of the present study it occurs during autumn when other tropical species appears, and consequently it can be considered as a sign of warm water.

(10) *Hemiaulus* EHRENBURG.

Hemiaulus generally contains four species, i.e. *H. Hauckii* GRUN., *H. sinensis* GREVILLE, *H. indicum* KARSTEN, and *H. membranaceus* CLEVE. Of these species the first three are found in Mutsu Bay. The commonest one is *H. Hauckii*.

Sp. 1. *Hemiaulus Hauckii* GRUN.

Though this is the commonest species of the genus *Hemiaulus* in Mutsu Bay its abundance is by no means high. On account of its meagre occurrence its seasonal occurrence is difficult to determine by the observation of a single year. But five year's investigation showed that the present species occurs in greatest abundance from August to October. It can also be found earlier or later than this season, though in very small number. The occurrence of *H. sinensis* is still less than that of the former species, and it may occur a little later in the season than the above species.

Hemiaulus indicus KARSTEN is a subtropical species and is a marked indicator of the Tsushima Current, occurring from September to October in limited number.

(11) *Hemidiscus* WALLICH.

Two species are included in this genus, i.e. *H. Hardmanianus* (GREV.) and *H. cuneiformis* WALLICH, both of which are subtropical being found in Mutsu Bay.

Sp. 1. *Hemidiscus Hardmanianus* (GRAV.) MANN.

In Mutsu Bay the occurrence of this species is limited to the warmest season, and its numerical abundance is very low. During four of the five years of the present study it was found only in very small numbers. In 1950, however, it occurred in greatest numbers during the period from September to December, though still not in large numbers. Relative abundance was noticed from November to early December. As this is a marked subtropical species its occurrence signifies the presence of the water mass of the Tsushima Current. As compared with another species, *H. cuneiformis* is by far less abundant. Although Akatsuka, in 1914, was able to find *H. cuneiformis* (as *Euodia cuneiformis*) at Takashima (Hokkaidô), he was not able to find any of *H. Hardmanianus*, probably because the latter is more stenothermal than the former, and hence not being distributed there.

(12) *Lauderia* CLEVE.Sp. 1. *Lauderia borealis* GRAN.

During the present investigation (1946–1950) this species was found to be very scarce, except during 1950 when it was found in abundance during November and December. Though the present species is named '*borealis*' Cupp (1943) states that the present species is a temperate one. In Mutsu Bay it seems to occur during warm season.

(13) *Leptocylindrus* CLEVE.Sp. 1. *Leptocylindrus danicus* CLEVE.

Leptocylindrus danicus CL. looks like a filamentous algae. Its period of abundance in Mutsu Bay is similar to that of *Lauderia*. In Mutsu Bay this species is found all the year round, but there is a tendency for it to be present in greater abundance from June to December. In 1949 and 1950 a moderate abundance was observed during June. Akatsuka (1914) stated that at Takashima its abundance is high during December to February.

(14) *Nitzschia* HASSAL.

Nitzschia is one of the most important genera of pelagic Diatoms. The following four species are found in Mutsu Bay; *N. seriata* CLEVE, *N. closterium* W. SMITH, *N. longissima* RALFS, *N. sigma* (KÜTZ.) W. SMITH, and *N. paradoxa* GRUNOW. The first one is the most common.

Sp. 1. '*Nitzschia seriata* CLEVE.

Nitzschia seriata CL. is an important species of pelagic Diatoms, its abundance is second to such important genera as *Chaetoceros*, *Rhizosolenia*, *Skeletonema*, etc. Though its cells are very minute its productivity is great, showing a vigorous vegetation every year in Mutsu Bay. Therefore it has a close bearing upon the productivity of the sea. During 1946–1950 its seasonal occurrence in Mutsu Bay was found to range over a period of from February to July, the maximum occurrence usually being found between April and June. It was present in highest abundance in 1949–1950; and in lowest in 1946.

There are two or three allied species which are indistinguishable from this species unless a close study is made of striae, kiel puncta, etc. Cupp stated the difficulties of avoiding confusing these species, and she suggested that these had been confused by earlier investigators. Despite its close similarity to some other species, it seems to differ from them in its ecology.

Nitzschia closterium W. SMITH is a not uncommon species found principally during the second half of the year. This suggests a warm temperate nature. But during other seasons, too, it is found sporadically. As compared to it *N. longissima* RALFS and *N. sigma* (KÜTZ.) W. SMITH are rare, probably its

seasonal occurrence being also during warm season of the year. Probably as a rare case the former species showed a moderate occurrence during March, 1946.

(15) *Rhizosolenia* (EHR.) BRIGHTWELL.

It is of interest to note that the genus *Rhizosolenia* is, on the whole, southern in its habits, except for some few species which are acclimatized to the northern environment. This may mean that the needle-like form of this genus is better adapted to warm water than to cold water. The present genus includes numerous species, and some of them are important because of their productivity. There are some species which are specially adapted to the tropical seas, and which are a strong indicator of the presence of warm water in northern districts.

In Mutsu Bay the following 16 species are found. The species marked by asteriks are important :

R. acuminata (H. PÉRAG.), *R. alata* BRIGHTW*, *R. Bergonii* H. PÉRAG*, *R. calcar avis* SCHULTZE*, *R. Castracanei* H. PÉRAG, *R. cylindrus* CLEVE*, *R. delicatula* CLEVE, *R. faeroensis* OSTENF., *R. fragilissima* BERGON*, *R. imbricata* BRIGHTW*, *R. imbricata* v. *shrubsolei* CLEVE*, *R. hebetata* (BAIL.) f. *semispina* (HENSEN)*, *R. robusta* NORMAN*, *R. setigera* BRIGHTW*, *R. Stolterfothii* H. PÉRAG*, *R. styliformis* BRIGHTW.

The number of species which were found in one collection ranged from 0 (in spring) to 10 (in autumn). From the monthly average observed during five years (1946-1950) it was found that from February to May the average number of species was 2 or 3, from June to August the number increased to 3 or 5, and from September on it increased to 5 or 10 species.

Of the 10 species given above 5 can be arranged in the order of numerical importance ; (1) *R. hebetata* f. *semispina* (HENSEN), (2) *R. alata* BRIGHTW. (3) *R. Stolterfothii* H. PÉRAG, (4) *R. setigera* BRIGHTW. (5) *R. imbricata* BRIGHTW.

Sp. 1. *Rhizosolenia hebetata* (BAIL.) f. *semispina* (HENSEN).

This is the commonest species of *Rhizosolenia* in Mutsu Bay, its abundance is very great as compared to the other species. Though it occurs during all seasons, vigorous vegetation occurs during the period of from April to August, and maximum flourishing is usually found in June. During the five years investigation the greatest abundance was observed in June, 1949. In short, as has been generally considered, this species is a warm-water form.

It is well known that *R. hebetata* has two forms i.e. f. *semispina* and f. *hiemalis*, the former being the warm-water form and latter cold-water form. It is notable that during the five years of the study f. *hiemalis* was never found during any season of the year. Probably the complete absence of f. *hiemalis* from Mutsu Bay is due to oceanographic conditions governed by the Tsushima Current. According to unpublished data collected by the author f. *hiemalis* has been found only twice

in past, once in 1925 and once in 1930. The occurrence of *f. hiemalis* in May and June, 1930 was especially prominent; it ranked first in abundance among the Diatoms, and *f. semispina* then ranked second in abundance.

An interesting finding concerning *R. hebetata* is Akatsuka's (1914). He reported that of the 500 individuals examined by him 473 were *f. semispina*, both terminals ending in a hair-like spine. In the cell of the remainder one end had the shape of *hiemalis*, terminating in a rounded spine, and true *f. hiemalis* with both ends rounded were not found. From this he conjectured the possibility of interchange between the above two forms. At any rate it is certain that in Japanese waters *f. hiemalis* is far less frequent than *f. semispina*. This is confirmed by Cupp's (1943) statement that *f. hiemalis* is rarely found further south than Alaska, in east Pacific.

Sp. 2. *Rhizosolenia alata* BRIGHTWELL.

In Mutsu Bay this species is second to the above one in abundance, being so abundant that its vegetation makes a large contribution to the productivity of the sea. Like *R. hebetata f. semispina* it occurs all the year around, but with a slight tendency to decrease vegetation between March and June. In Mutsu Bay its maximum occurrence is usually found between September and November, when the other tropical species appear. It has been well established that this is an oceanic species and consequently in Mutsu Bay its abundance signifies the arrival of the Tsushima Current from the Tsugaru Strait. On the basis of its ecology in Mutsu Bay the author believes that this species is more southerly in nature than the preceding species.

Sp. 3. *Rhizosolenia Stolterfothii* H. PÉRAGALLO.

Rhizosolenia Stolterfothii H. PÉRAG. ranks third in abundance in Mutsu Bay. It has a tendency to show a moderate increase during autumn, but its frequency is relatively stable during all seasons, as compared with the above two species. During the 5 years of the present study it showed a moderate vegetation only in November, 1950, no marked occurrence having been observed in other years.

Sp. 4. *Rhizosolenia setigera* BRIGHTWELL.

Rhizosolenia setigera is a little lower in abundance than are the preceding species. Its seasonal distribution is almost uniform. During the present investigation no remarkable vegetation was observed through any year, but an increase may occur around June, like *R. hebetata f. semispina*.

Sp. 5. *Rhizosolenia imbricata* BRIGHTWELL.

Of the five important species of *Rhizosolenia* of Mutsu Bay this species is the least abundant. The seasonal distribution of this species is not so marked as other species, and it is generally thought to be north temperate in habits. During the years 1946-1950, and especially during 1949, it showed a tendency

to increase from December on. Though it is improbable that this species is absent from Hokkaidô, Akatsuka (1914) did not find it, in his study at Takashima.

Sp. 6. *Rhizosolenia cylindrus* CLEVE.

In Mutsu Bay three tropical *Rhizosolenia* are found *R. cylindrus* CL., *R. acuminata* (H. PÉR.) GRAN, and *R. castracaenici* H. PÉRAGALLO. Of these, *R. cylindrus* is the most distinct representative of the tropical species, though of course the others are also useful indicators of the presence of warm water. Comparing with the two others, which are huge in size, *R. cylindrus* is extremely small, its diameter measuring only 8–13 μ . Numerically, *R. cylindrus* is least frequent; other two sometimes occur in moderate abundance.

Seasonally, the above three species occur from August to October. Differing from other tropical Diatoms, these three species seem to be peculiar in that they does not occur in any period other than that above mentioned.

(16) *Skeletonema* GREVILLE.

The genus *Skeletonema* usually contain two pelagic species: *Skeletonema costatum* (GREV.) and *Skeletonema mirabile* GRUN. Of these two species the former is incomparably more common than the latter.

Sp. 1. *Skeletonema costatum* (GREV.) CLEVE.

Skeletonema costatum is a cosmopolitan and neritic in nature, its distribution ranging from tropical to boreal seas. It is characterized by its extremely small cells (3.5–18 μ), but in numerical abundance and in power of vegetation it is next to *Chaetoceros*. Therefore whether or not the present species propagates, it largely influences the productivity of the sea. The author reported (1931–1940) that this species was extremely abundant at Takashima (Hokkaidô) and at Fuzan (Korea), the maximum abundance at Takashima being found to be 5,298,000 cells per litre of water on June 1st, 1931. As a further prominent example Bush (1916) found 369,000,000 per litre at Laboe in Kiel Bay in June, 1906.

As respects the seasonal occurrence of this species the author reported (1931–1940) that during the summer of 1931 it occurred in great abundance over a vast area from Formosa to Hokkaidô, Bigelow (1926) also found it in great abundance in the Gulf of Maine during summer and autumn. Fish (1925), however, stated that at Woods Hole this is a winter species. Matsue (1934) also found it in great abundance at Misaki during winter. Such a disagreement may be due to the fact that the vegetation of this species can also be caused by factors other than the temperature, e.g. nutriment and light.

In Mutsu Bay the seasonal occurrence of this species is not always very distinct. But the general trend is that it increases from June on, and shows maximum occurrence in November or later. In 1949 this tendency was specially clear, and the absence or sparse occurrence of this species during the early

half of the year was marked. As has been stated elsewhere Mutsu Bay is warmest in late autumn, so the above feature of the occurrence of this species indicates that it is a warm water species. Moreover earlier research by the author (1931-1940) found this species to be present everywhere around Japan during the warm season.

As to the autecology of this species Karsten's classical experiment is well known. Cultural experiment made by him showed that under still conditions the intercellular spines of this species became extremely shortened, while under moving conditions the spines became very much lengthened. Matsue's (1936) study on the change of size of this species is of interest. According to him, in Shinagawa Bay, *Skeletonema costatum* reduces its size during summer and increases its size during winter, the change well according with the change of physical conditions which govern the buoyancy of Diatoms. In contrast to the above study Ekusa (1947) who studied the same species at Atsumi Bay reported that it reduces size during winter and increases the size during summer. Regarding this discrepancy Ekusa has commented that the size of Diatoms may be principally related to the adaptation for floatation, but at the same time, may also be affected by the division of the frustule which inevitably leads it to size-reduction.

(17) *Thalassionema* GRUNOW.

Superficially this genus is closely allied to the genus *Thalassiothrix*, and formerly it was included in the latter. The main difference is in its isopol apical axis which in *Thalassiothrix* is heteropol. Only one species is included in this genus.

Sp. 1. *Thalassionema nitzschioides* GRUNOW.

Thalassionema nitzschioides is an ubiquitous species, one of the commonest pelagic Diatoms in Mutsu Bay, sometimes showing a high abundance. Though it occurs all the year round, it has a tendency to increase from September on and it shows maximum abundance during October and November. This tendency was observed most markedly during 1950. This is the general tendency in Mutsu Bay, but when the occurrence of the species is meagre through the whole year it is absent or scarce during the early half of the year. Such a tendency was reported earlier by the author (Kokubo, 1932) and it suggests that this species is neither boreal nor arctic. Bigelow (1926) however, reported in 1926 that in the north European waters this species occurs most abundantly from February to April and is at its minimum in August.

Sometimes the present species reduces its apical length extremely, its colony becoming like that of *Diatoma* or *Tabellaria* in appearance. In some other cases its cells more or less curve, in its girdle view, and it had been called *Thalassiothrix curvata* CASTR. until this was emended as a form of *Thalassionema*. This form is also found very often in Mutsu Bay.

(18) *Thalassiothrix* CLEVE and GRUNOW.

This genus includes two common species; *Thalassiothrix frauenfeldii* GRUN. and *Thalassiothrix longissima* CLEVE & GRUN., of which the former is the more common in Mutsu Bay.

Sp. 1. *Thalassiothrix frauenfeldii* GRUNOW.

Thalassiothrix frauenfeldii is also one of the commonest species of the Diatoms of Mutsu Bay. Its numerical abundance is markedly less than that of *Thalassionema nitzschioides*. The seasonal distribution ranges from September to February, maximum occurrence usually being found in October. During other seasons of the year its occurrence is very scanty or it is absent. The presence of this species after December is due to the survivors from autumn. On the whole the present species is of more southerly nature than *Thalassionema nitzschioides*.

Thalassiothrix longissima CLEVE & GRUNOW is less abundant than the above species. During the present study no remarkable occurrence was found. Though it is found through the whole year in very small numbers there seems to be slight tendency to occur from late summer on.

III. SUMMARY.

- 1) The results presented in this paper comprise two thirds of the work (Chap. 1, General part and Chap. 2, Diatoms) done under the general title of the present paper. The remaining third (Chap. 3, Zooplankton) has been postponed until the next issue.
- 2) In the present work the net-plankton has been studied exclusively, and the special importance was attached to the ecology of the Diatoms and Copepods.

The quantitative collections were made by using a ordinary tow net, disregarding the filtration ratio. The result showed that it is a good method to obtain data for studying the relative changes in the quantity of plankton.

- 3) In Mutsu Bay the plankton repeat a regular seasonal change which can be summarized as follows:

During January and February the plankton decrease in quantity and in species; during March and April the plankton increase in quantity largely because of the vernal vegetation of Diatoms; during May and June the boreal plankton, represented by the *Copepoda*, *Sagitta*, etc. occur, though their abundance varies, year by year, more or less irregularly; during July and August local warm-water plankton appear, though generally they are low in abundance; during September and November two important events occur; the occurrence of tropical plankton and the autumn vegetation of Diatoms; from mid-November to December the plankton gradually decrease.

- 4) The regular occurrence of the tropical plankton in Mutsu Bay is a remarkable phenomenon. This decidedly shows the arrival of the warm-water mass from the south during this season. As to why it occurs in autumn and not in summer, it can be accounted for by the low velocity of the Tsushima Current which conveys the tropical plankton.
- 5) Comparing the plankton of Mutsu Bay to those of the west coast of Hokkaidô, it is remarkable that in the latter locality the tropical plankton are extremely meagre. The relative abundance of the tropical plankton in both locality probably signifies the relative strength of Tsushima Current in both locality.
- 6) In Mutsu Bay Diatoms develop two vegetations a year, i.e. the spring and the autumn vegetation. Generally the former is by far more prominent than the latter, though in some cases it is vice versa. In some years it also happens that the autumnal vegetation takes the form of two or three successive flourishings, instead of one vigorous vegetation. In such cases the earlier vegetation is mostly due to the flourishing of warm-water species; the later one due to that of cold-water species.
- 7) As is generally known plankton shows a change from year to year in a definite area. In Mutsu Bay there are two distinct periods, i.e. constant period and varying period, each of which occurs twice each year. In constant periods (spring and autumn) similar plankton occur from year to year, showing no change. In varying periods (early summer and early winter) different plankton appear from year to year, showing distinct changes. As to what plankton appear in these four periods (spring constant period, summer varying period, autumn constant period, and winter varying period), and as to what cause develops such periods an account was given elsewhere.
- 8) In the present study 126 species (32 genera) of Diatoms have been found. Of these Diatoms the most important genera are enumerated, in order of numerical importance, as follows: *Chaetoceros*; *Nitzschia*; *Coscinodiscus*; *Skeletonema*; *Rhizosolenia*; *Asterionella*; *Biddulphia*; *Thalassiothrix*.
- 9) Among the above genera, *Chaetoceros* was most important in its specific and quantitative abundance. The number of the species of *Chaetoceros* found in Mutsu Bay during 1950 was 51. Adding, however, 7 species which were found in other years the species amount to 58 in all.

Of these the ones which are so abundant as to affect the productivity of the sea are the following:

<i>Ch. affinis</i>	<i>Ch. debilis</i>	<i>Ch. distans</i>
<i>Ch. decipiens</i>	<i>Ch. didymus</i>	<i>Ch. socialis</i>
<i>Ch. subsecundus</i>	<i>Ch. constrictus</i>	

- 10) In Mutsu Bay there appear Diatoms which indicate the warm-water mass of the Tsushima Current. These are the tropical and subtropical species of *Chaetoceros*, *Climacodium*, *Hemiaulus*, *Hemidiscus* and *Rhizosolenia*. There

also occur several species of plankton which signify the presence of water mass of cold current. The particulars of these indicator species have been reported elsewhere.

Literature cited

- 1) Aikawa, H. 1936. The planktological Properties of the principal Sea-areas surrounding Japan (Bull. Jap. Soc. Sci. Fish., Vol. 5, No. 1, pp. 34-41).
- 2) Akatsuka, K. 1914. Plankton Diatoms of Takashima Region (Rep. Fish. Exp. St. Hokkaidô. No. 9) (in Japanese).
- 3) Allen, W. E. & E. E. Cupp. 1935. Plankton Diatoms of Java Sea (Annales du Jardin Botanique de Buitenzorg, Vol. 44. Pars 2).
- 4) Allen, W. E. 1945. Seasonal Occurrence of Marine plankton Diatoms of Southern California in 1938 (Bull. Scripps Ins. Oceanog. Univ. Calif., Vol. 5, No. 3, pp. 293-334).
- 5) Bush, W. 1916. Über das Plankton der Kieler Förde in Jahre 1912-13 (Wissens. Meeresunt., N. F. Bd. XVIII, Abt. Kiel, pp. 28-142).
- 6) Calif. Acad. Sci. etc. 1950. California Cooperative Sardine Research Program (Mar. Res. Committee, State of Calif.).
- 7) Cupp E. E. 1943. Marine Plankton Diatoms of the West Coast of North America (Bull. Scripps. Inst. Oceanog. Univ. Calif., Vol. 5, No. 1, pp. 1-238).
- 8) Ekusa, S. 1949. Size Variations in Plankton Diatoms and some Considerations of their ecological Significans (Bull. Jap. Sci. Fish., Vol. 15, No. 7, 332-336).
- 9) Ferguson, Wood. 1951. Phytoplankton Studies in Eastern Australia (Indo-Pacific Fisheries Council Proceedings. 2nd Meeting. Apr. 1950, Cronulla, W.S.W., Australia).
- 10) Frost, N. 1938. The genus *Ceratium* and its use as an Indicator of Hydrographic conditions in Newfoundland Waters (Res. Bull., No. 5, pp. 1-15. Dept. Nat. Resou. Newfoundland Government).
- 11) Gran H. H. 1905. Diatomeen (Nordishes Plankton, XIX, Botanisher Teil).
- 12) Gran, H. H. & E. C. Angst. 1930. Plankton Diatoms of Puget Sound (Bull. Puget Sound Biol. St., Vol. 7, pp. 417-516).
- 13) Hustedt. Fr. 1930. Die Kieselalgen Deutshland, Österreich u. d. Schweiz. I-III Teil (Rabenforst's Kryptogamen Flora von Deutschland, Österreich u. d. Schweiz. Bd. VII).
- 14) Iizuka, A. 1950. Seasonal and yearly Fluctuation of *Ceratium* in Oshoro Bay and their Oceanographic Consideration (Sci. Papers of Hokkaidô Fish. Sci. Inst., No. 7, pp. 106-116).
- 15) Ikari, J. 1926-1928. On some Chaetoceros of Japan. I-II. (Bot. Mag., Vol. 40, No. 478, pp. 517-543, Vol. 42, No. 497, pp. 247-262).
- 16) Kokubo, S. 1929. Studies on the Plankton of the Tsugaru Strait (The Zool. Mag., Vol. 38, No. 455, pp. 296-309) (in Japanese).
- 17) „ 1931a. A quantitative Investigation of the Plankton of Aomori Bay, as studied comparatively by Pump and Net Collection (Sci. Rep. Tohoku Imp. Univ., 4th Ser. Biol., Vol. VI, No. 3, pp. 491-531).
- 18) „ 1931b. Quantitative Studies on the Plankton of Aomori Bay (The Zool. Mag., Vol. 43, No. 115, pp. 558-585).
- 19) „ 1931-1940. The Journal of Plankton. No. 1-15 (National Research Council of Japan) (in Japanese).

- 20) „ 1932a. Quantitative Studies on the Microplankton in Aomori Bay During 1929-1930 (Records Oceanog. Works in Japan, Vol. IV, No. 1, pp. 171-244).
- 21) „ 1934. On the seasonal and vertical Distribution of the Plankton of Aomori Bay (Sci. Rep. Tohoku Imp. Univ., 4th Ser. Biol. Vol. VIII, No. 4, pp. 297-333).
- 22) Kokubo, S. & T. Tamura. 1938. Observations on the Plankton and Hydrographic conditions of Aomori Bay during the Period 1933-1935 (Record Oceanog. Works in Japan, Vol. X, No. 1, pp. 1-15).
- 23) Kokubo, S. 1939. Quantitative Studies of the Neritic Littoral Microplankton of Japan collected at sixteen Stations ranging from Saghalien to Formosa, 1931-1933 (Proc. Sixth Pacific Sci. Congr., Berkeley, Stanford, San Francisco, July-Aug., Vol. III, pp. 541-564).
- 24) „ 1945-1949. Bulletin of the Marine Biological Station of Asamushi. Vol. 1-5.
- 25) „ 1950. On the Plankton of Mutsu Bay (Bulletin of the Research of Fisheries Resource of Aomori Prefecture. Vol. 1, pp. 99-122).
- 26) Lebour, M. V. 1930. The Plankton Diatoms of Northern Seas.
- 27) Matsue, Y. 1936. On the Seasonal Form-variation of a pelagic Diatom, *Skeletonema costatum* (Journ. Sea and Sky. Vol. 16, pp. 225-230, No. 6) (in Japanese).
- 28) Motoda, S. et al. 1950. On the Distribution of the Plankton in the western Sea Area of Hokkaidô during the Summer of 1929 (Rep. Deep Sea Fish. Res. Comm., pp. 80-109) (in Japanese).
- 29) Okamura, K. 1907. Some Chaetoceros and Peragallia of Japan (Bot. Mag. Tokyo, Vol. XXI, No. 244).
- 30) „ 1911. Some littoral Diatoms of Japan (Rep. Imp. Fish. Inst., Vol. 7, No. 4, pp. 1-18).
- 31) Russel, F. R. 1939. Hydrographical and Biological Conditions in the North Sea as indicated by Plankton Organisms (Jour. du Conseil. Vol. 14, No. 1, pp. 171-192).
- 32) Sato, T. 1913. On the Pelagic Copepoda. Pt. I (Rep. Fish. Exp. St. Hokkaidô, No. 1) (in Japanese).
- 33) Sverdrup, H. U. & E. E. Allen. 1940. Distribution of Diatoms in Relation to the Character of Water Masses and Currents off southern California in 1938 (Sears Found. Jour. Mar. Res.).
- 34) Ueda, M. 1931. Of the monthly oceanographical Charts of the adjacent Seas of Japan based on the Averages for the thirteen Years from 1918-1930, with a Discussion of the Current System Inferred from these Charts (Jour. Imp. Fish. Exp. St., No. 2, 1931).
- 35) Ueda, M. 1945. Studies on the Plankton of Uranouchi Bay (in Japanese, Occasional mimeograph print. pp. 1-30).
- 36) Ueda, M. 1950. On the Hydrographical Conditions of Uranouchi Bay (in Japanese, Publ. Kôchi Prefecture).
- 37) Ueno, F. & Ogawa. 1950. Reports of the Plankton off Shionomisaki in Aug. 1949 (Publ. Kôbe Marine Observatory) (in Japanese).
- 38) „ 1951. Prompt Report on the Plankton. No. 5 (Publ. Kôbe Marine Observatory) (in Japanese).

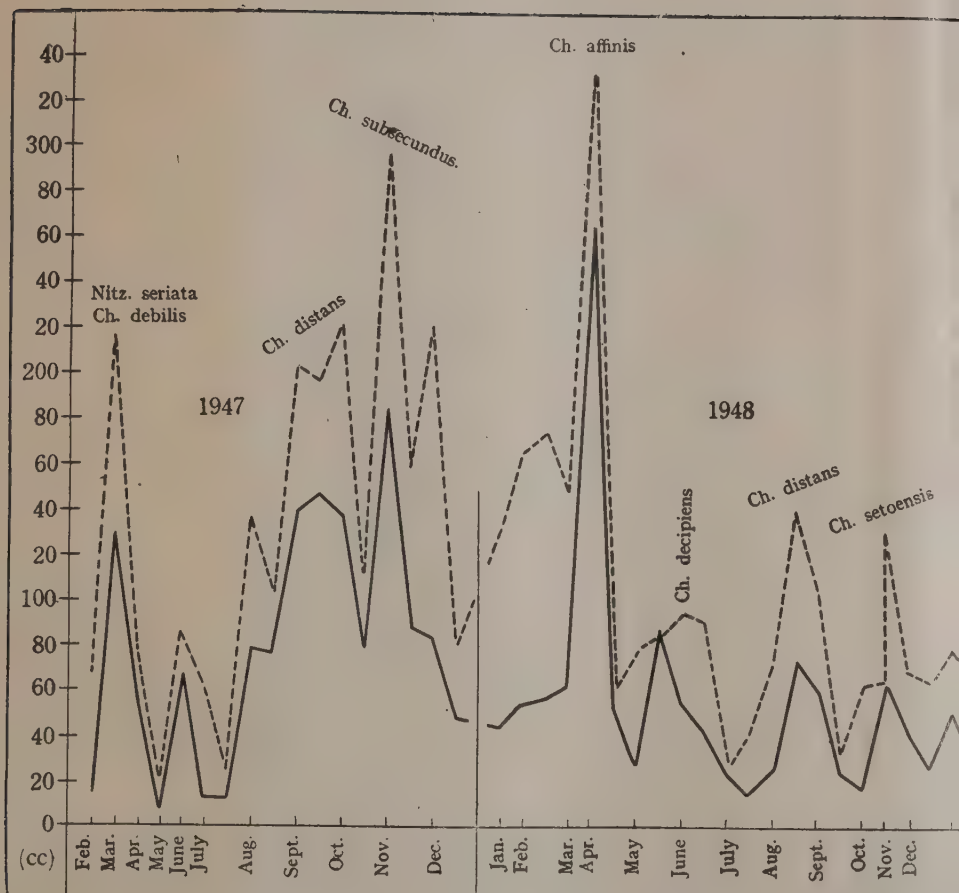
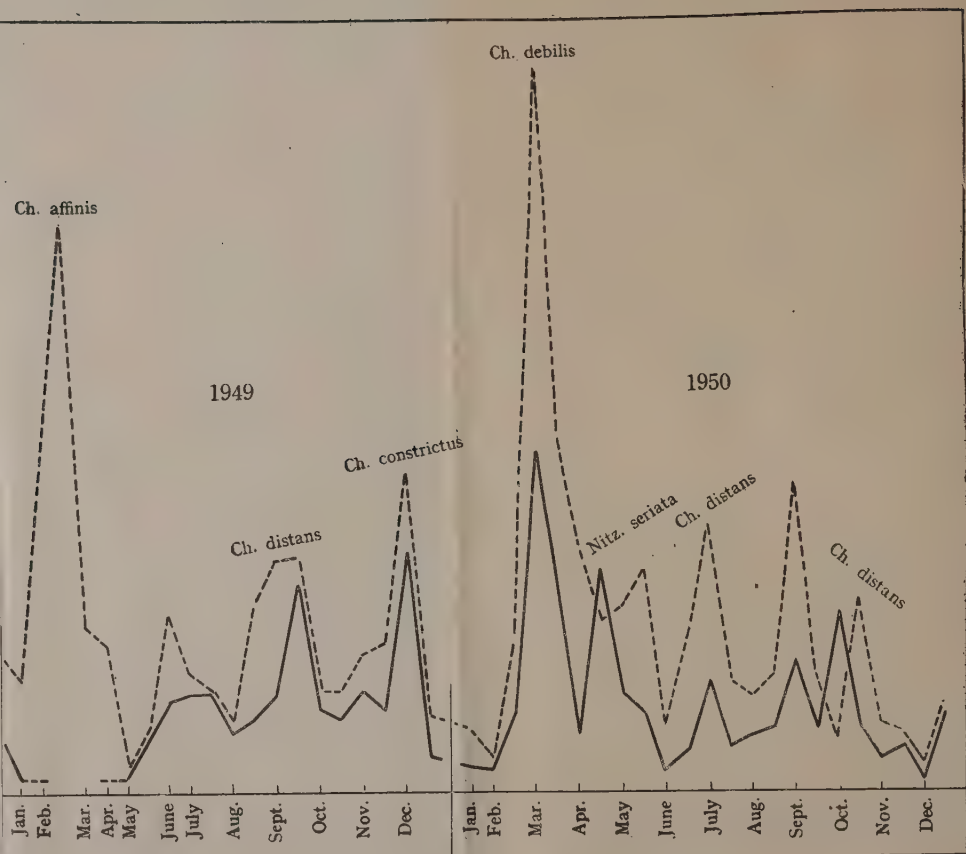


Fig. 1. Quantitative change of plankton during the period 1947-1948.
 Ordinate—relative volume of plankton(cc) (of p. 5 and 6).
 Dotted line—horizontal collection; Species name denoted above the line.



from 1947 to 1950.

(d p. 8); Abscissa — month ; Continued line — vertical Collection ;

tes the plankton of absolute majority.

1947					1948			
Date	Vol. in cc				Vol. in cc			
	Vert.	0m	10m	Mean	Date	Vert.	0m	10m
Jan	—	—	—	—	13rd	45	130	135
Feb. 15th	16	75	63	69	12nd	54	183	146
					28th	58	195	153
Mar. 14th	130	236	198	217	15th	62	172	125
Apr. 8th	55	66	97	82	1st	265	453	215
					18th	53	49	45
May 8th	7	24	13	19	1st	27	49	105
					18th	87	135	28
June 1st	68	59	114	87	5th	55	12	74
					21st	41	95	87
July 13rd	12	95	30	63	10th	23	31	15
25th	13	9	19	14	28th	14	53	24
Aug. 7th	79	132	147	140	11th	24	75	65
18th	77	100	107	104	31st	75	193	87
Sept. 4th	140	235	170	205	15th	60	87	123
19th	148	240	158	199	29th	23	30	31
Oct. 3rd	138	207	235	221				
15th	87	136	83	109	15th	17	67	59
Nov. 9th	185	245	350	297				
29th	88	187	130	159	16th	65	113	148
Dec. 9th	84	295	148	222	5th	42	43	95
27th	48	110	48	79	17th	27	33	79
					21st	51		78
Mean	80	144	119	134		62	128	101

Relative volume of plankton

Table I.

Mean	1949					1950				
	Vol. in cc					Vol. in cc				
	Date	Vert.	0m	10m	Mean	Date	Vert.	0m	10m	Mean
133	15th	8	70	36	53	14th	12	31	30	33
165 174	25th	—	243	185	264	3rd 16th	11 36	14 54	13 85	14 69
149	18th	—	67	67	67	6th 19th	158 95	405 177	287 153	339 165
334 47	14th	—	66	73	70	1st 16th	27 101	99 38	127 120	113 79
77 82	4th 19th	7 24	8 15	13 32	11 23	2nd 17th	46 36	66 103	109 106	87 105
96 91	25th	43	107	62	84	4th 15th	11 20	29 82	28 60	29 71
23 41	3rd 23th	44 46	42 47	69 50	56 48	6th 21st	52 21	132 54	125 47	129 51
70 140	2nd 14th	27 34	37 71	22 107	31 89	4th 15th	26 30	48 56	39 53	44 55
105 31	3rd 15th	45 99	113 97	103 121	108 110	7th 23rd	61 29	136 57	152 54	144 55
63	2nd 18th	38 37	66 55	24 36	45 45	3rd 15th	84 30	34 96	24 83	90 25
131	12th 18th	47 40	71 80	56 60	64 70	3rd 18th	15 21	21 26	40 33	31 30
69 65 78	3rd 19th	113 17	90 34	209 37	150 36	4th 16th	6 37	10 38	18 46	14 42
103	Mean	42	73	77	75		42	63	79	79

during successive years of 1947-1950.

No.	Species	1950	Jan.		Feb.		Mar.		Apr.		2
			14th	3rd	16th		6th	19th	1st	16th	
1	<i>Chaetoceros affinis</i>		RR	RR	RR					RR	
2	<i>Ch. aff. f. circinalis</i>										
3	<i>Ch. aff. f. singularis</i>										
4	<i>Ch. aff. v. Willei</i>									RR	
5	<i>Ch. anastomosans</i>										
6	<i>Ch. atlanticus</i>		RR	RR			RR	RR			
7	<i>Ch. borealis</i>		RR		RR		RR	RR			
8	<i>Ch. brevis</i>										
9	<i>Ch. coarctatus</i>										
10	<i>Ch. concavicornis</i>		RR	RR	RR		RR	RR	RR	R	
11	<i>Ch. concav. f. volans</i>				RR		RR	RR	RR		
12	<i>Ch. constrictus</i>		RR	RR	RR		+	+	R	+	
13	<i>Ch. convolutus</i>										
14	<i>Ch. compressus</i>		RR	RR	RR		+	R	R	R	
15	<i>Ch. costatus</i>										
16	<i>Ch. crinitus</i>									RR	
17	<i>Ch. curvisetus</i>				RR						
18	<i>Ch. danicus</i>										
19	<i>Ch. debilis</i>		C	C	CC		CC	CC			
20	<i>Ch. decipiens</i>		R	R	RR		RR	RR			
21	<i>Ch. decip. f. singularis</i>										
22	<i>Ch. denticulatus</i>										
23	<i>Ch. densus</i>			RR	RR		RR				
24	<i>Ch. didymus</i>		RR	RR	R		RR	RR	RR		
25	<i>Ch. didy. v. angulicus</i>										
26	<i>Ch. distans</i>									RR	
27	<i>Ch. Lauder</i>										
28	<i>Ch. diversus</i>										
29	<i>Ch. Lorenzianus</i>		RR	RR	RR		RR				
30	<i>Ch. messanensis</i>										
31	<i>Ch. mitra</i>										
32	<i>Ch. nipponica</i>										
33	<i>Ch. paradoxum</i>										
34	<i>Ch. pendulus</i>		RR	RR	RR		RR			RR	
35	<i>Ch. peruvianus</i>										
36	<i>Ch. pseudocurvisetus</i>										
37	<i>Ch. radians</i>		R	RR	RR		RR	R		RR	
38	<i>Ch. radicans</i>										
39	<i>Ch. rostratus</i>										
40	<i>Ch. setoensis</i>		RR		RR						
41	<i>Ch. siamense</i>										
42	<i>Ch. socialis</i>										
43	<i>Ch. subsecundus</i>		RR	RR	R		RR	+	R	RR	
44	<i>Ch. teres</i>						RR	RR	RR	RR	
45	<i>Ch. tetrastichon</i>										
46	<i>Ch. tortissimus</i>										
47	<i>Ch. Van Heurckii</i>										
48	<i>Ch. Weissflogii</i>			RR							
49	<i>Chaetoceros</i> sp. 1										
50	<i>Chaetoceros</i> sp. 2										
51	<i>Chaetoceros</i> sp. 3.										

Seasonal occurrence of each species

Table II.

May	June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
17th	4th	15th	6th	21st	4th	15th	7th	22nd	3rd	15th	3rd	18th	4th	16th
+	RR		RR	+	RR	R	RR	R RR	C	C	RRz		C	C
RR		RR	RR			RR	RR	RR	R RR	RR				
				RR	RR		RR	RR		RR RP	RR	RR	RR	
						RR								RR
RR RR RR				RR R	R	+	RR	R	RR RR	RR R	RR	R	R	
									C	+	RR	RR	RR	RR
RR C RR	RR	RR	+	RR R	RR +	RR +	R	+	RR +	RR CC	RR CC	+	R CC	R +
			RR	RR	RR	RR	RR	RR	RR	RR	RR +	RR RR	RR RR	RR RR
RR			RR	+	+	+	+	+	RR RR	R RR	RR	RR		R
			C RR	CC RR	CC R		CC RR	CC RR	CC RR	R RR +	RR	RR	RR RR	R RR
							RR	RR	R		R RR	RR	RR RR	R RR
RR	RR	RR	RR		RR	RR	R			RR	RR RR	RR	RR RR	RR
			RR	RR	RR	R	RR	RR	RR		RR			
										RR RR				
RR										RR RR	R RR RR		RR R C +	
									RR +	RR RR RR	RR	RR	RR	
													RR RR	

of Chaetoceros, denoted in relative abundance.

No	Species	1950	Jan.			Feb.			Mar.		Apr.		21
		14th	3rd	16th	6th	19th	1st	16th					
52	<i>Amphora quadrata</i>												
53	<i>Amphora</i> sp.												
54	<i>Actinoptychus undulatus</i>		RR	RR	RR								
55	<i>Asterionella japonica</i>		+	+	+	+	+						
56	<i>Asteromphalus heptactis</i>			RR									
57	<i>Bacteriasterum comosum</i>												
58	<i>Bact. delicatulum</i>												
59	<i>Bact. hyalinum</i>												
60	<i>Bact. minus</i>												
61	<i>Bact. varians</i>				RR								
62	<i>Bacteriastrium</i> sp.												
63	<i>Biddulphia aurita</i>		RR	R	+	RR	RR						
64	<i>Bidd. longicrustis</i>												
65	<i>Bidd. mobilensis</i>												
66	<i>Bidd. sinensis</i>		R	RR	RR	RR	RR						
67	<i>Camphylodiscus undulatus</i>												
68	<i>Cerataulina Bergonii</i>												
69	<i>Climacodium biconcavum</i>												
70	<i>Cl. Frauenfeldianum</i>												
71	<i>Corethron criophilum</i>		RR	RR	RR	RR							
72	<i>Coscinodiscus Angatii</i>		RR	R	RR								
73	<i>Cosc. asteromphalus</i>												
74	<i>Cosc. concinnus</i>		RR	R									
75	<i>Cosc. excentricus</i>		RR		RR								
76	<i>Cosc. Granii</i>			RR	RR								
77	<i>Cosc. radiatus</i>		RR	RR	RR	RR	RR	RR	RR	RR	RR		
78	<i>Cosc. Waileii</i>		RR	RR	RR	+	RR			RR	RR		R
79	<i>Coscinodiscus</i> sp. 1		RR										
80	<i>Coscinodiscus</i> sp. 2				RR								
81	<i>Coscinodiscus</i> sp. 3												
82	<i>Cyclotella</i> sp.												
83	<i>Dactyliosolen tenuis</i>					RR							R
84	<i>Diploneis elliptica</i>												
85	<i>Dip. adonis</i>												
86	<i>Diploneis</i> sp.												
87	<i>Ditylum Brightwellii</i>		RR	RR	RR	RR							
88	<i>Eucampia zoodiacus</i>			RR			RR			RR	RR	RR	R
89	<i>Guinardia flaccida</i>												
90	<i>Hemiaulus Hauckii</i>			RR	RR								
91	<i>Hem. sinensis</i>												
92	<i>Hemidiscus Hardmanianus</i>												
93	<i>Hemid. cuneiformis</i>												
94	<i>Lauderia borealis</i>				RR								
95	<i>Lau. annulata</i>												
96	<i>Leptocylindrus danicus</i>						RR						RI
97	<i>Licmophora lyngbyei</i>												
98	<i>Navicula distans</i>				RR								
99	<i>Navicula</i> sp.												
100	<i>Nitzschia closterium</i>			RR		RR				RR			
101	<i>Nitz. longissima</i>		RR										
102	<i>Nitz. seriata</i>		RR	RR	RR	+	C	C	CC	CC			CC
103	<i>Nitzschia</i> sp.			RR									
104	<i>Plagiogramma</i> sp?												RI
105	<i>Pleurosigma affine</i>		RR	RR						RR	RR		RI
106	<i>Ple. elongatum</i>												
107	<i>Rhizosolenia alata</i>			RR	RR					RR	RR		
108	<i>Rhiz. Bergonii</i>												
109	<i>Rhiz. calcar avis</i>				RR								
110	<i>Rhiz. Castracaenei</i>												
111	<i>Rhiz. cylindrus</i>												
112	<i>Rhiz. imbricata</i>		+	RR	+								
113	<i>Rhiz. hebetata f. semispina</i>						R						RF
114	<i>Rhiz. robusta</i>		RR	RR	RR								
115	<i>Rhizz. setigera</i>		R	RR	RR	RR	RR	RR	RR	RR	RR		R
116	<i>Rhiz. Stollerfothii</i>		RR		RR	RR							RF
117	<i>Rhiz. styliiformis</i>												
118	<i>Skeletonema costatum</i>					RR	RR	RR					RF
119	<i>Stephanopyxis palmeriana</i>				RR								
120	<i>Thalassiosira aestivalis</i>			R		RR	RR	RR					
121	<i>Thal'sra hyalina</i>		RR	RR	R	RR	RR						
122	<i>Thal'ra</i> sp.												
123	<i>Thal'ra Nordenskyöldii</i>												
124	<i>Thal'nema nitzschoides</i>		R	RR	RR	RR	RR	RR			RR		RF
125	<i>Thalassiothrix Frauenfeldii</i>		RR	RR	RR								
126	<i>Thal'rix longissima</i>												
127	<i>Trochiscia Clevei</i>			RR	RR	RR	RR	RR	RR	RR			RF
128	<i>Halosphaera viridis</i>												
129	<i>Trichodesmium erythrium</i>												

Seasonal occurrence of each spec

Table III. (continued)

[illegible]

ies of Diatoms. denoted in relative abundance.

On the Dissolved Oxygen and Chlorinity of the Water of Mutsu Bay during 1950

By

Toshinobu Tokui

Quantity of Chlorine.

Because Mutsu Bay is connected with the open sea by the Tairadate Strait which is less than 10 km in width, the bay is like a lagoon and owing to the drainage of fresh water from the land the quantity of chlorine is variable throughout the year. Especially the surface layer is largely affected. Observations on the variation in quantity of chlorine at definite stations in 1950 show that the quantity from January to March in the 10-30 m layer was invariable but the surface layer was subject to some change. In April the surface layer showed a remarkable low value owing to the water from the snow melt of the Hakkoda mountains being carried by every stream and river into the bay; this condition continues to the early part of May.

From the latter part of June to the early part of July there is again a low value in the quantity of chlorine owing to the surface layer being supplied with water of the rainy season. In August and September the heat from solar radiation causes an increase in evaporation, thus the surface layer showed a high value, but during the latter part of September the observed value of the surface layer showed high salinity which became lower toward the bottom layer owing to the fact that in autumn the water of low salinity in the surface layer descends to the bottom layer because of the lowering of water temperature. After this season to March of the following year each forms layers. In general the change in chlorine quantity in Mutsu Bay as stated above is repeated yearly. The quantity of chlorine for each year depends upon the strength of the open sea current, amount of water drained from the land and other phenomena. Details concerning the aforementioned are reserved for another opportunity.

Oxygen Content

The change in oxygen content throughout the year of 1950 in Mutsu Bay shows that during the winter season of January and February it was about 6.50 cc/L but oversaturation never occurs. Because of the low water temperature and bad weather during the winter season the waves stir up the water, thus

Table 1. Chlorine Content of Sea water in Mutsu Bay during 1950.

Depth (m)	Cl (%)											
	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	VI.15	VII.6
0	18.70	18.07	18.57	18.52	18.42	16.78	14.66	15.85	18.07	18.12	17.15	17.31
5	18.72	18.57	18.68	18.55	18.61	18.58	18.00	18.18	18.48	18.49	18.36	18.19
10	18.72	18.68	18.68	18.63	18.63	18.64	18.54	18.52	18.50	18.51	18.45	18.39
20	18.72	18.68	18.68	18.63	18.63	18.70	18.61	18.47	18.58	18.51	18.48	—
30	18.72	18.68	18.68	18.63	18.63	18.72	18.68	18.39	18.58	18.51	18.48	18.60
	VII.21	VIII.4	VIII.15	IX.7	IX.23	X.3	X.15	XI.3	XI.18	XII.4	XII.16	
0	16.72	18.45	18.32	18.67	18.68	18.26	18.49	17.69	17.61	18.22	17.78	
5	18.23	18.58	18.66	18.72	18.68	18.49	18.52	18.49	18.35	18.57	18.35	
10	18.39	18.69	18.70	18.76	18.67	18.57	18.57	18.51	18.47	18.67	18.49	
20	18.49	18.71	18.68	18.76	18.67	18.59	18.57	18.51	18.53	18.67	18.67	
30	18.60	18.74	18.79	18.80	18.65	18.60	13.55	18.51	18.59	18.68	18.67	

Table 2. Oxygen Content and its Saturation in Sea water of Mutsu Bay during 1950.

Depth (m)	Oxygen (cc/L)										
	I.14	II.3	II.16	III.5	III.19	IV.1	VI.16	V.2	V.17	VI.4	
0	6.26	6.56	6.53	7.28	7.06	7.26	7.12	6.54	6.50	6.21	
5	6.27	6.45	6.54	7.27	6.97	7.17	7.18	6.66	6.69	6.36	
10	6.33	6.49	6.55	7.21	7.02	7.25	7.45	6.78	6.69	6.39	
20	6.36	6.59	6.56	7.23	7.10	6.94	7.51	7.09	6.70	6.28	
30	6.30	6.50	6.49	7.15	6.98	6.70	7.44	6.58	6.47	5.75	
	VII.21	VIII.4	VIII.15	IX.23	X.3	XI.3	XI.18	XII.4	XII.16		
0	5.26	5.00	4.66	4.80	5.14	5.58	5.79	5.86	6.21		
5	5.26	5.42	4.62	4.91	4.97	5.33	5.65	5.70	6.14		
10	5.34	5.46	4.69	5.06	4.88	5.30	5.60	6.69	6.01		
20	5.43	5.44	4.94	5.06	4.93	5.24	5.56	5.67	5.99		
30	4.95	5.19	4.89	5.02	4.76	5.24	5.42	5.71	5.90		

Depth (m)	Oxygen (%)										
	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	
0	94.6	95.9	98.9	106.0	103.5	108.0	105.0	97.5	103.5	103.4	
5	94.7	96.0	98.8	106.1	103.7	109.0	111.5	102.5	108.8	106.4	
10	95.6	96.7	99.1	105.4	104.0	108.2	114.8	106.3	109.5	105.6	
20	96.1	97.3	99.2	106.2	104.6	103.3	113.4	113.6	109.8	101.9	
30	95.2	96.0	98.2	105.0	102.6	98.8	112.2	107.9	107.5	92.6	
	VII.21	VIII.4	VIII.15	IX.23	X.3	XI.3	XI.18	XII.4	XII.16		
0	100.8	99.2	94.7	93.0	96.6	94.9	95.9	95.1	95.5		
5	101.3	104.8	94.3	95.2	94.3	92.9	94.6	95.2	97.5		
10	100.4	103.2	93.6	97.9	92.1	92.3	94.4	95.8	96.5		
20	101.5	101.7	96.5	97.9	94.1	91.2	94.1	95.5	97.7		
30	92.0	95.4	91.4	97.1	90.8	91.2	91.9	96.1	96.2		

the oxygen content can be said to be rather large. In March the increase in solar radiation ; vegetation of coastal sea-weeds, and an increase in plant plankton, carbon assimilation causes an increase of more than 7 cc/L, thus the percentage saturation exceeds 100% to reach a condition of oversaturation. The maximum value of oxygen in Mutsu Bay appears during this season. In the summer season, because of the increase in water temperature and chlorine content and decay of organisms, the quantity of oxygen decreases down about to 4.5 cc per litre, thus in early autumn, a minimum value is found. In late autumn together with the increase of autumn diatoms and decrease in water temperature there is an increase of oxygen content. This condition continues to the March of the following year. The change in oxygen content in Mutsu Bay throughout the year is as stated above. The quantity of oxygen is affected by the physical properties (temperature, salinity), biological conditions (plant plankton), wind, waves and tides, therefore to understand the slight changes or annual differences further study is necessary.

Report on the Water Temperature of Mutsu Bay during 1950

Teruyoshi Kawamura

This article is a report on the observations of water temperature of Mutsu Bay during January to December, 1950.

a). Results from the previous year: In the report for 1949 (Bulletin of Marine Biology, vol. 4, nos. 2, 3, 4), it was expressed that the water temperature compared with normal years, was higher during January to March, lower during April to August and normal thereafter, except for a lowering in December. This abnormality is due to the general lowering of water temperature during 1949, resulting from the strong cold-water current from the Japan Sea.

b). Conditions of the water temperature during 1950: The results of the present observations following the general lowering of the previous year are shown in the following table.

Temperature and Specific Gravity of Mutsu Bay during 1950.

Depth (m)	Temperature (°C)											
	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	VI.15	VII.6
0	8.08	6.86	7.80	6.49	6.82	8.53	9.29	8.87	11.09	14.00	16.78	21.29
5	8.09	7.68	8.14	6.71	7.56	8.43	9.71	9.29	11.73	13.01	14.69	19.44
10	8.08	7.51	8.21	6.72	7.23	7.64	9.15	9.91	12.10	12.67	13.20	18.33
20	8.06	7.13	8.19	6.74	7.04	7.54	8.22	11.01	12.19	11.65	12.75	18.24
30	8.08	7.11	8.17	6.79	6.97	6.97	8.12	12.28	12.77	11.29	12.38	17.34
Mean of Om, 10, 30m, (A)	8.08	7.16	8.06	6.67	7.01	7.71	8.85	10.35	11.99	12.65	14.12	18.99
Mean of 1927 ~1947 (B)	7.52	6.88	6.17	—	6.10	6.72	7.58	9.07	10.55	12.13	14.02	16.29
Difference between A and B	0.56	0.28	1.89	—	0.91	0.99	1.27	1.28	1.44	0.52	0.10	2.70
	VII.21	VIII.4	VIII.15	IX.7	IX.23	X.3	X.15	XI.3	XI.18	XII.4	XII.16	
0	22.46	23.49	25.39	27.79	21.87	20.16	19.43	14.94	13.18	11.83	9.45	
5	21.83	21.80	25.39	23.57	21.85	20.65	19.38	16.47	14.09	13.02	10.69	
10	20.18	20.25	23.84	22.98	21.27	20.17	19.41	16.45	14.29	13.40	11.11	
20	19.63	19.67	22.37	22.77	21.76	20.82	19.45	16.47	14.47	13.40	11.82	
30	19.25	18.61	19.62	22.30	21.50	20.82	19.49	16.47	14.58	13.40	11.83	
Mean of Om, 10, 30m, (A)	20.58	20.78	22.95	23.02	21.55	20.38	19.44	15.95	14.35	12.88	10.79	
Mean of 1927 ~1947 (B)	18.31	21.27	22.10	22.62	21.78	20.52	18.80	16.57	14.77	12.07	10.54	
Difference between A and E	2.27	-0.49	0.85	0.40	-0.23	-0.14	0.64	-0.62	-0.42	0.81	0.25	

Depth (m)	Specific Gravity (σ_{15})											
	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	VI.15	VII.6
0	26.20	25.70	24.78	24.60	24.62	22.29	19.87	21.25	24.11	24.18	23.17	23.65
5	26.20	26.30	24.80	24.74	25.02	24.61	23.82	24.27	24.61	24.74	24.78	24.40
10	26.20	26.50	24.84	24.81	24.99	24.80	24.57	24.51	24.81	24.94	24.86	24.58
20	26.20	26.40	24.84	24.81	24.99	24.85	24.83	24.51	24.81	25.05	24.93	—
30	26.20	26.50	24.84	24.81	24.99	24.85	24.86	24.51	25.08	25.20	24.98	24.89
Mean of Om, 10m, 30m.	26.20	26.23	24.82	24.74	24.87	23.98	23.10	23.42	24.67	24.77	24.34	24.37
	VII.21	VIII.4	VIII.15	IX.7	IX.23	X.3	X.15	XI.3	XI.18	XII.4	XII.16	
0	23.05	24.86	24.75	25.07	24.86	24.60	24.63	23.09	—	24.18	23.61	
5	24.88	24.98	25.40	25.14	24.97	24.88	24.93	25.00	—	24.71	24.34	
10	24.88	25.20	25.40	25.16	25.10	25.05	25.01	25.02	—	24.91	24.58	
20	25.22	25.29	25.42	25.24	25.10	25.10	25.03	25.02	—	24.98	24.82	
30	25.45	25.39	25.47	25.26	25.12	25.12	24.70	25.02	—	24.98	24.82	
Mean of Om, 10m, 30m.	24.46	25.15	25.21	25.16	25.30	24.92	24.78	24.38	—	24.69	24.34	

The difference between the maximum and minimum water temperatures for 1950 and the normal years is as follows 0.56°C (Jan. 14), 0.28°C (Feb. 3), 1.89°C (Feb. 16), 0.91°C (Mar. 19), 0.99°C (April. 1), 1.27°C (Apr. 16), 1.28°C (May 2), 1.44°C (May 17), 0.52°C (June 4), 0.10°C (June 15), 2.70°C (July 6), 2.27°C (July 21), -0.49°C (Aug. 4), 0.85°C (Aug. 15), 0.40°C (Sept. 7), -0.23°C (Sept. 23), -0.14°C (Oct. 3), 0.64°C (Oct. 15), -0.62°C (Nov. 3), -0.42°C (Nov. 18), 0.81°C (Dec. 4), 0.25°C (Dec. 16).

Thus, from the differences in water temperature it is noticed that the maximum raise of 2.70°C occurred on July 6, followed by 0.62°C on July 21, 0.49°C on August 4 and 0.42°C on November 11, in the order given. During the latter half of the period of observation cases of low temperature were recorded but during the former half of the period, the water temperature remained high. As noticed from Table, considerably low temperature is observed in Mutsu Bay during November, but during the period of observation (23 times) low temperature was recorded only five times. The remaining observations showed the water temperature to be higher than that of the normal years. These results indicate that the water temperature for 1950 was higher than that of normal years.

The fluctuation in water temperature of Mutsu Bay is due chiefly to the strength of the cold and warm water currents flowing into the bay from the Japan Sea. The high water temperature of Mutsu Bay this year is due to the superiority of the warm water current flowing into the bay from the Japan Sea.

c). Water temperature and catch of codfish in Mutsu Bay: The water temperature of Mutsu Bay around the tenth of December is 11°C, thus the cold water plankton *Chaetoceros debilis* and *Ch. socialis* predominate. In the early latter part of November when the sea reaches this cold water condition in normal years the catch of codfish is believed to be good. However during November of

1950 the cold water plankton consisted predominantly of *Chaetoceros decipiens* and *Ch. didymus*, and *Ch. debilis* and *Ch. socialis* were not abundant, thus, it was judged that the conditions for codfish were not suitable. From the results of the previous year, it was presumed that the conditions for catching codfish were insuitable. Accordingly, the presumption was justified as the catch of codfish during the latter part of December was low, in fact, the lowest hitherto recorded.

Seasonal Change of the Phosphate and Silicate of the water of Mutsu Bay during 1950

Tetsusaburō Okitsu

I. Introduction

The hydrographical and plankton conditions of the water temperature, specific gravity and oxygen content in Mutsu Bay have been observed monthly at definite stations for many years at the Marine Biological Station of the Tohoku University.

However, there are but few reports concerning the nutritious salts which have direct bearing on the food consumed by organisms. The writer, under the supervision of Professor Kokubo, has continued research since 1948 on the P_2O_5 and SiO_2 of nutritious salts. The results have been published in Bulletin of The Marine Biological Station of Asamushi. Taking this opportunity, the writer reports on the results of 22 observations made during January to December of 1950.

Observations were made at a fixed station, that is, about two nautical miles offing the station at the depth of about 30 meters. Analysis of P_2O_5 was done according to W. R. G. Atkin's method (modified from Denige's method), and for the standard SiO_2 solution, 39 mg of picric acid dissolved in one litre was used. The colorimetre used is the Tomiyama colorimetre.

Acknowledgements are due to Professor Kokubo, Director of the Marine Biological station of Asamushi, Tōhoku University, for his kind supervision throughout the course of the present study.

II. Results

(1). P_2O_5 The conditions of P_2O_5 in the present observations is shown in the following table.

The P_2O_5 in the surface layer during the winter period of January to February was in the limits of $12\gamma/L$, but in early March it decreased to $3\gamma/L$. Immediately thereafter there was a slight recovery, but with the progress of the season the decrease became remarkable, and in mid-summer the content became nullified. However, in October recovery again occurred, and in the middle of the same month the content reached about $7\gamma/L$. This condition of P_2O_5 continued to the end of the year.

Quantity of Phosphate (γ/L) in Mutsu Bay during 1950.

Depth (m)	Date											
	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	VI.15	VII.6
0	7/L	12	11	3	5	6	6	4	2	2	4	2
5	8	13	8	6	7	4	3	5	4	3	4	7
10	11	8	12	6	7	6	4	3	3	3	8	7
20	8	10	10	6	7	5	4	7	4	6	8	—
30	11	13	13	6	7	8	5	7	8	15	12	9
Mean	10	11	11	5	7	6	6	5	4	6	7	6

	VII.21	VIII.4	VIII.15	IX.7	IX.23	X.3	X.15	XI.3	XI.18	XII.4	XII.16	
0	7/L	3	0	0	0	3	7	5	—	6	6	
5	2	5	0	0	0	4	7	5	—	6	8	
10	3	7	0	0	0	4	7	5	—	5	8	
20	2	5	10	3	11	7	11	6	—	4	9	
30	16	14	20	14	19	7	11	9	—	4	9	
Mean	6	6	7	3	6	5	9	6	—	5	8	

The SiO_2 and chlorine content in the surface layer is clearly due to the effect of land water, but in the case of P_2O_5 no effect was noticed at any the observation stations.

The quantity of P_2O_5 of the middle layer as well as their seasonal variation was almost the same as in the case of the surface layer.

The bottom layer during the winter period of January to February was 13 γ/L , thus showing a value similar to the surface layer. In early March the value decreases to about 6 γ/L . During the spring season the value of 6 γ/L was nearly constant, but in early summer a remarkable increase was recognized and in mid-summer or August 15 the value of 20 γ/L was reached, thus attaining the highest value for the year. However, in October a decrease was again recorded, being nearly equal to the quantity of the spring season: this continued to the end of the year.

The vertical distribution during the winter season is quite uniform but during the spring and autumn there is a tendency of it gathering in the bottom layer. In the summer season the tendency becomes strong and although middle layer is almost avoid of it, the bottom layer shows an increase and reaches the maximum value of the year.

In the summer season as can be seen from the conditions of water temperature in this bay, retardation is remarkable. Therefore the quantity of P_2O_5 which gathers in the upper layer is slight, the plankton quantity in the upper layer is great, the assimilation considerable and the quantity of used P_2O_5 is great, thus the vertical distribution in summer is strong.

The decrease of P_2O_5 on March 5 corresponds to the spring flourishing of plankton. In the autumn season or in the early part of September when the

flourishing of plankton begins, the decrease in P_2O_5 is not so remarkable as in the case of the spring season. However, the decrease of P_2O_5 caused by the plankton in autumn is overcome by the increase in the rate of regeneration.

Checking the observed values of the fixed stations it is noticed that the quantity of P_2O_5 attains 40–20 γ/L at the most and that when the consumed quantity is great the quantity of P_2O_5 decrease to a very small amount or becomes nullified. In fact, the quantity of P_2O_5 is very small in general in this bay.

The quantity and the seasonal variation of P_2O_5 in Mutsu Bay is as mentioned above, but since the depth range of this bay is like a small basin, the quantity of the nutritious salts accumulated in the bottom layer may be not great, however, because the circulation and stirring of the water is strong, the velocity of revolution of salts is increases, probably, the regenerated P_2O_5 revolves so that it may be consumed by the plankton.

(2). SiO_2 The conditions of SiO_2 during the present observations is as shown in the following tables.

Quantity of Silicate (γ/L) in Mutsu Bay during 1950.

Date												
Depth (m)	I.14	II.3	II.16	III.5	III.19	IV.1	IV.16	V.2	V.17	VI.4	VI.15	VII.6
0	γ/L											
5	675	1,150	544	175	306	1,413	2,578	956	469	338	963	1,163
10	1,125	813	475	100	287	321	487	344	318	206	275	719
20	950	800	469	175	262	269	263	181	313	213	250	663
30	675	838	488	312	456	384	463	569	450	538	650	—
Mean	825	875	480	292	325	288	463	744	494	869	850	1,200
	850	895	491	216	327	535	851	559	409	433	598	936
	VII.21	VIII.4	VIII.15	IX.7	IX.23	X.3	X.15	XI.3	XI.18	XII.4	XII.16	
0	γ/L											
5	1,288	225	575	194	250	350	400	953	—	625	1,095	
10	475	200	225	144	200	288	350	363	—	312	525	
20	238	238	263	153	225	225	288	363	—	269	444	
30	238	313	288	231	269	225	288	381	—	269	394	
Mean	663	463	763	444	488	225	475	381	—	331	450	
	580	288	423	233	286	263	360	488	—	361	582	

From January to the early part of February the distribution in the upper and lower layers is uniform, the quantity being 800 γ/L . In middle February the quantity of each layer decreases suddenly to about one half that of January. In early March the quantity showed a marked decrease to 200 γ/L .

After the spring season the decay of the quantity in the surface layer was remarkable, that is, compared with the layer deeper than 5 m. the quantity was great. The maximum of 2,578 γ/L was reached on April 16, and the minimum of 194 γ/L on September 7. The decay of SiO_2 in the surface layer is not season decay, but due to the temporary variation caused by water from the land.

This variation had no effect on the 5 m. deep layer. The quantitative proportion of SiO_2 of the surface layer and Cl' seemed to be parallel.

The conditions of SiO_2 of the middle layer compared to that of the surface layer was remarkable but the quantity was small and the decay was not outstanding. In March there was a sudden decrease of SiO_2 to about 200 γ/L , but thereafter there was not much change, 200–300 γ/L being continued until the middle of December when there was a raise to around 400 γ/L .

The quantity of the bottom layer was, in general, like that of the upper layer, but in June to September the accumulated quantity was great and thus settled to the bottom layer but it was not as strong as in the case of P_2O_5 .

The outstanding decrease from the middle of February to middle March cannot be ascribed to the flourishing of spring plankton. Hereafter the conditions extended to the autumn without any noteworthy increase. The seasonal variation is due to the circulation of regenerated SiO_2 consumed by the plankton.

III. Summary

- (1). This article reports on the seasonal variation of the quantity of P_2O_5 and SiO_2 in Mutsu Bay during January to December of 1950.
- (2). The quantity of P_2O_5 in each of the layers was about 10 γ/L during the winter season. In the summer season the stratification is remarkable, the upper layer having the value of nothing or only a very small quantity, while the bottom layer was about 20 γ/L .
- (3). The SiO_2 content in the surface, due to the land water sometimes exceeded 2,000 γ/L , but generally in the winter season it was 800 γ/L and in the summer season 200–300 γ/L .
- (4). In general, the quantity of P_2O_5 and SiO_2 can be thought to be small because of the shallow water body and to the rapid circulation of these salts being consumed by the plankton.

THE MARINE BIOLOGICAL STATION OF ASAMUSHI

Aomori Prefecture, Japan

(Subjecting to Tôhoku University, Sendai)

Resident Members

Seiji Kokubo, Prof., Director, D.Sc., (Planktologist)
Tetsusaburô Okitsu, Ass'nt, B.Sc. (Planktologist)
Fumitaka Tsubata, Ass'nt, B.Sc. (Bio-Hydoreographer)
Toshinobu Tokui, Ass'nt, (Chemist)
Saburô Kokubo, Ass'nt, M.Sc., B.Sc. (Biologist)

Biological Staff in Tôhoku University

Prof. Dr. Shichiroku Nomura (General Physiology)
Prof. Dr. Isao Motomura (Embryology)
Prof. Dr. Arika Kimura (Botany, Systematic)
Prof. Dr. Mutsuo Kato (Zoology)
Prof. Dr. Tadao Jimbo (Botany, Ecology)
Prof. Dr. Masayuki Nagao (Botany, Physiology)

(On basis of March, 1952)

研 究 者

- (1) プランクトン — 小久保清治, 沖津哲三郎
- (2) 物理的条件 — 津幡文隆
- (3) 化学的条件 — 沖津哲三郎, 徳井利信
- (4) 総 括 — 小久保清治

昭和27年5月31日印刷

昭和27年6月1日発行

編集兼 東北大学浅虫臨海実験所
発行者 青森県浅虫

印刷所 笹氣出版印刷株式会社
仙台市場通 27番地
電話 2027, 2207
